PROCEEDINGS

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XXXV. *Note on the Index of Refraction of Ebonite.* *By* W. E. AYRTON *and* JOHN PERRY*.

IN a note communicated to the Royal Society (printed in 'Nature,' No. 596, vol. xxiii. March 31, 1881), we described how, by using a selenium cell, lent us by Mr. Bidwell, and a pair of delicate Bell's telephones, we had succeeded in showing, 1st, that there was refraction when intermittent radiation from the oxyhydrogen light passed through an ebonite prism; and, 2ndly, that the index of refraction of that ebonite was approximately 1·7.

Exceedingly great care had to be taken, in consequence of the feebleness of the sounds given out by the telephones; and, from the nature of the experiment, we obtained the index of refraction for that narrow band of rays which experienced least absorption.

Shortly after these results were published, Prof. Fitzgerald, of Dublin, suggested, in conversation, the possibility of checking them by measuring the polarizing angle of light reflected from ebonite, on the assumption that the refracted ray is at right angles to the reflected one when giving maximum polarization. Subsequently Dr. Jellett was so kind as to make these experiments, the results of which Prof. Fitzgerald per-

* Read June 25, 1881.

mits us to quote. The mean index of refraction for ebonite thus obtained, on Fresnel's theory, was 1·611.

Later on we repeated our selenium experiments, replacing the intermittent oxyhydrogen light with an intermittent electric light, and increasing the electromotive force in the selenium telephone-circuit to about 60 volts. A confirmation of our former result was obtained; but, although we were able to take greater precautions to ensure accuracy, we obtained no more than a confirmation; and from the difficulty of hearing the weak sounds in the telephones, we felt that the index of refraction thus measured might be as much as 1·8 or as small as 1·6.

In the course of these experiments, however, it was noticed that visible red rays were certainly refracted; and consequently we proceeded to make measurements according to ordinary optical methods, using the apparatus shown in the figure. L (fig. 1) is a fairly powerful electric light produced by a Gramme machine; C is a glass lens giving a parallel beam of light, part of which passes through the slit, S, $\frac{1}{20}$ inch wide, and falls on the edge of the ebonite prism P. F is a frame

Fig. 1.

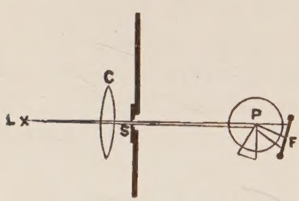
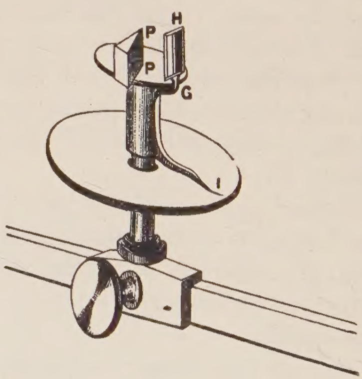


Fig. 2.



holding tissue-paper, which can be moved about P as centre, and which carries an index, I, pointing to the graduations on the circle, as seen in fig. 2. There was a fine vertical line in the middle of the tissue-paper; and HG, forming about one third of the paper, was well blackened. First this screen was moved into such a position that the edge of the prism threw a

black shadow which was bounded by the fine central line, and between that line and the blackened portion H G was a thin band of white light. In fact a narrow beam from the slit fell on the edge of the prism; and half was stopped by the prism, the other half going on. The index-reading in this position was taken; and now the screen was moved round until a red spectrum was seen. At the least-refrangible end this spectrum terminated nearly abruptly, as the ordinary visible spectrum usually does; and this end was made to coincide with the central line in the screen, and the index-reading taken when, after moving the prism itself, it was supposed that we had minimum deviation. The index-reading was also taken in the same way for the most-refrangible end of the visible spectrum; but as this did not die away at all abruptly, and as the whole spectrum was very faint, the second set of measurements merely gives a rough idea of the amount of spectrum that was visible. The mean of a number of observations made by different observers, and the results of which were closely in accord, gave 1·66 as the index of refraction for the well-defined least-refrangible end, and 1·9 as the average result for the badly-defined most-refrangible end.

As the slit in the metal diaphragm used with the selenium experiments had to be much wider than that employed with the simple light-experiments, we cannot of course tell what exact part of the spectrum produced the sound: probably it was at about the least-refrangible end of the visible spectrum; but it may have been the dark rays just beyond.

Summing up the results of the various experiments, we have for the index of refraction of certain specimens of ebonite:—

Ebonite prism, selenium, and telephones . .	about 1·7
Measurement of polarizing angle by reflection	„ 1·611
Least refracted end of visible spectrum produced by ebonite lens having an angle of 28°·5 . about	1·66

In a paper by Captain Abney and Colonel Festing, recently read before the Physical Society and printed in the Philosophical Magazine for June, on the Transmission of Radiation through Ebonite, reference is made to our original experiments; and the authors say that, judging from the figure accompanying our Note, they should think that the thickness

of the ebonite prism traversed by the intermittent beam must have been about one fourth of an inch. We are afraid that that figure is liable to give this misconception; in drawing it we were merely paying attention to the directions of the incident and refracted beam, and not to the actual thickness of the ebonite, which was in fact very small indeed where the intermittent beam passed through it.

XXXVI. *The Microphonic Action of Selenium Cells.* *By* Dr. JAMES MOSER*.

WHEN I began these researches on the Transformation of the Energy of Light into that of Sound by the Photophone, I held the opinion which is still common, that there are two kinds of photophones and three forms of light-rays. My experiments led me to the conclusion that there is only one way in which light acts photophonically. The effect of radiation on selenium cells is, in fact, the same as that exerted on the majority of solid, liquid, and gaseous bodies used as non-electric photophonic receivers. Though rays may have different wave-lengths, all rays are the same in kind. There are not three kinds—heating, luminous, and chemical, but one and the same ray may have heating, chemical, and luminous effects.

In February last, when I began these experiments, I believed that the photophone could inform us as to the direct correlation between light and electricity. A current circulating around a beam of polarized light changes the plane of its vibration. Hence we are led to conjecture that there may exist further relations between light and electricity, and that, as the electric current or lines of magnetic force affect the beam, so, inversely, the beam may influence the electric current or the magnetic lines of force; and we may conjecture that such influence may manifest itself in the photophone.

I therefore tried to change the magnetic condition of an iron plate by light. I hoped, for instance, to get an electric current in the coil of the telephone at the moment when

* Read June 25, 1881.

its iron plate is exposed to radiation. I did not succeed in observing such a current.

Prof. W. G. Adams was the first to show that selenium on illumination develops an electromotive force. Still supposing that in the photophone a direct correlation between the energy of light and that of the electric current might reveal itself, I endeavoured to observe and to measure the electromotive force developed in selenium cells on their exposure to light.

I made selenium cells according to the method of Bell and Tainter as modified by Bidwell. Two thin copper wires were wrapped parallel side by side several times round a strip of mica. Selenium was then melted, and crystallized between them. In this way I obtained cells which were very sensitive and yielded, when connected with the battery, a clear sound in the telephone. According to my last measurement, the resistance of one of those cells in the dark is 3000 ohms, diffuse daylight reducing it to 2700. The measurements were made with an astatic-mirror galvanometer, the resistance of the coils of which was 6860 ohms. The scale was about one metre distant from the mirror, each division one fortieth of an inch. There were other galvanometers at my disposal, and a battery of twenty Leclanché cells. The galvanometer proved itself more sensitive than the telephone.

The above-mentioned selenium cell yielded by intermittent radiation of lime- or electric light clear and distinct sounds; illumination by the same sources of light deflected the image of the slit strongly.

But the same light which, when a current of an external battery flows through the cell, makes the telephone to sound or the spot of light to slide along the whole scale, is not able to produce an observable electromotive force in the selenium cell. This non-appearance of a current (the circuit being formed only of selenium cell and galvanometer, or of selenium cell and telephone) is, in my opinion, very noteworthy; for the problem which I wish here to solve is not to make photophones without batteries, but to explain the efficiency of the selenium cells by the qualities they actually possess.

It is possible to prepare pieces of selenium which show an electromotive force on being illuminated. I shall return to

this point further on. But cells and pieces of selenium *not* possessing this property nevertheless show photophonic action. Therefore the photophonic action cannot be explained by this property, which is, or at least may be, wanting in the selenium cells.

I proceeded further, always endeavouring to find a correlation of the energies. The current flowing through a selenium cell experiences a counter force—a polarization. I tried to observe, and, as far as possible, to measure it. This polarization is shown by *all* my cells and preparations of selenium. I found it, however, when measured by the compensation method, to be only about the thousandth of a volt. In order to observe the polarization as near as possible to its maximum, I employed a rotating switch, which I constructed by means of two alternating tooth-wheels, and which changed the current eighty times per second.

I next endeavoured to increase the electromotive forces originating in the selenium cell, as well as those produced eventually by light. I tried to attain this by taking the two wires of different material; then I prepared selenium pieces where selenium was simply between two straight parallel wires. At first I made a selenium cell, just like the one described above, replacing, however, the one copper wire by one of platinum, so that the selenium was between copper and platinum. But the polarization, which again could be easily observed, was here also very small. On measuring, it was found again about one thousandth of a volt. Also this cell did not produce, either in the dark or on illumination, any current which could be observed by the galvanometer.

In order to increase the polarization, I gave the polarized selenium cell greater capacity. I took, instead of the wires, two larger plates, each 6 centim. long, 3 centim. wide, and about 1 millim. thick. My intention was to begin the experiments with three of such pairs, with

copper, selenium, copper;
zinc, selenium, zinc;
zinc, selenium, copper.

With the latter of these cells I succeeded (after having sent through it the current of a strong battery) in observing

a polarization of about 0·4 volt. The cell had now become a polarization battery, giving rise to a current long after it was separated from the primary battery.

In all these experiments, and especially in the last, a superposition of polarizations could be distinctly observed; so that here we have to deal, not simply with thermo-electric currents, but with electro-chemical decomposition.

An observation, however, which I now made gave a different direction to these researches. But their aim remained unchanged—namely, to explain the efficiency of the selenium cells, to understand the transformation of energy of light into that of sound in the selenium cell, regarding it from a more general point of view and not merely as an isolated phenomenon in selenium, but, by finding the general law, to remove selenium from its isolated position. This, however, may be done either by comparing other bodies with it (which is the method of previous investigations on the subject, and was my own also till now), or this may be effected by inserting selenium in the series of other bodies. The latter method I shall now describe.

I intended to make such cells of copper, selenium, copper, or of zinc, selenium, copper plates, in the same way as the above-described photophonic cells. On a copper plate I melted amorphous selenium, and put on it the second metal plate of zinc or copper. Then I heated gradually, so that the selenium became crystalline; and I then annealed it. Whilst the amorphous selenium adheres very well to the metal plates, these cells proved very brittle when the selenium was crystalline; the selenium always split off from the copper plate. In order to find how to avoid this splitting-off, I examined the matter more closely; thus, I left out the second metal plate, and experimented with copper and selenium only.

The preparation was, in accordance with that of the photophonic cells, the following:—One of the copper plates to be used for the cells was heated on a large brass plate of about 3 millim. thickness; this was covered by a thin sheet of mica, on which the selenium which eventually flowed off was collected. The copper plate having reached the melting-point of amorphous selenium, was covered with this substance and thereupon removed from the brass plate. On being re-

moved it cooled quickly; and on it now a black brilliant layer of amorphous selenium remained. The larger brass plate having also cooled, the copper plate covered with selenium was again laid on it and again slowly warmed, so that the selenium crystallized. The temperature was still further raised, near to the point at which the crystalline selenium begins to melt. The selenium was then annealed.

But, notwithstanding this caution, it was not possible to fix the selenium on the copper plate. It exfoliated and split off. Every lamina which exfoliated was on the upper side light grey, and on the lower side blue-black, not brilliant but dull. In the same way the copper plate had now a similar dull blue-black covering. This blue-black body is cuprous selenide, Cu_2Se. There were thus three layers—copper, cuprous selenide, and selenium; and in the copper-selenium-zinc cell two other layers—selenide of zinc and zinc; so that all together there were five layers.

I took thinner copper plates; but the splitting-off still occurred.

This experiment shows that between the copper and the selenium, or rather the cuprous selenide, there is only a slight and imperfect contact.

But the same is the case in the photophonic cell. In this also the three layers—copper, cuprous selenide, selenium—follow one after the other. The plates give only an enlarged view of what is to be observed in the photophonic cell on a smaller scale, and with more difficulty, by the eye. Thus we see that in the photophonic selenium cell also we have only a similar slight and imperfect contact, which is to be influenced by radiation. It was first by this experiment that it became obvious to me that a microphonic effect is the essential part of the action of the selenium cells.

I was confirmed in this conclusion, that *the selenium photophone is a microphone,* when I learned that Mr. Sumner Tainter had constructed a photophone in which selenium was replaced by carbon. Indeed his apparatus, the zigzag line filled with carbon on the silver-coated glass plate, is nothing else than a microphone. If we remember the apparatus described by Mr. Hughes as a thermoscope, we understand that the selenium photophone of Messrs. Graham Bell and Sumner Tainter

agrees in its principle with the carbon photophone of the latter; and, again, this is in its main features the same as the thermoscope.

Thus my attention became now more directed to those passages in the literature where the degree of the resistance at the surfaces of contact between the selenium and the metal, in comparison with the total resistance, is discussed.

In 1875, before the invention of the microphone, Dr. Werner Siemens observed a high resistance at the surfaces of contact. He arrived at the conclusion "that an essential part of the resistance of the selenium is in its limiting layers at the surfaces of contact" *.

Mr. Sabine is of the same view. Finding, *e. g.*, in one piece of selenium with several transversal platinum wires the resistances of the junctions to be 429, 479, 498, and 428 megohms, the resistance of the selenium itself between the wires, however, much smaller (22, 13, and 0 megohms), he remarks:—"It is clear from these measurements that a large portion of the observed resistance of a so-called selenium resistance may, and frequently does, reside in the junctions, and not in the selenium. Therefore the larger we make the surface of contact between the platinum and the selenium, the less likely are we to find an otherwise sensitive piece of selenium rendered comparatively insensitive by the introduction of high junction resistance. In this respect the form of selenium plate designed by Dr. Werner Siemens, in which the platinum wires form gratings or interlying spirals, is unquestionably the best form to employ when the object in view is to obtain a high sensitiveness to light" †.

Both authors assume the selenium to possess a special sensitiveness, and this quality to be damaged by the high resistance of the junctions. Therefore they aim at annihilating this resistance at the surfaces of contact. Aiming at this annihilation, they enlarge the surfaces of contact and thus diminish the resistance.

The surfaces of contact should indeed be enlarged. The reasons, however, for which this must be done are, in my opinion, just the opposite to those influencing these two

* Pogg. *Ann.* clix. p. 140.

† 1878, Phil. Mag. (5) v. p. 404.

observers. It is the high resistance at the junctions which is the variable, and which is necessary for the microphonic action. The case of this resistance alone being the variable I shall discuss immediately. That the resistance at the junctions is high is a necessary consequence of the imperfect and variable contact. To annihilate it is to render the photophone insensitive. And, *vice versâ*, the more extensive the surfaces of contact are, the more sensitive is the selenium cell.

A further strong support, amongst others, is given to this theory by the observation of Mr. Bidwell *, who has made very numerous experiments with selenium cells. "He got the best speech from cells of high total resistance . . . The selenium should, however, have a low specific resistance."

These observations are easily understood by the microphonic action of the cells ; for, that the total resistance is to be great and yet the specific resistance of the selenium is to be small, has no other meaning than that there must be a bad contact between good conductors.

The next question is, if this microphonic action is confined only to the surfaces of contact. I must here recall that Messrs. Draper and Moss †, distinguishing three crystalline modifications of selenium, observe as to their conductivity, "Between these two forms of granular selenium—the apparently nonconducting and the comparatively highly conducting—there is another, of intermediate resistance. This modification is highly sensitive to light."

Just so, according to Rammelsberg ‡, selenium exists in four allotropic modifications, three of which are crystalline.

For evidence of the microphonic action I was at first contented to observe that selenium in this crystalline state, in which it is most brittle and the most powdery, is also most sensitive to light. Afterwards I succeeded in obtaining a piece which shows this very clearly. Between two platinum wires of 3 centim. length was a selenium plate 8 millim. in width and hardly 1 millim. in thickness. Heated in air and annealed, the whole surface had taken the light grey colour of a crystalline state; half the upper surface, on

* London Phys. Soc. Jan. 22, 1881; Tel. Journ. ix. p. 52.
† 1873, Proc. Irish Ac. (2) i. p. 533, Nov. 10.
‡ 1874, Pogg. *Ann.* clii. p. 151.

the side of the one platinum wire, was smooth and continuous; the other half, near the other platinum wire, was powdery and granular. Alternately one of the two halves was kept constantly dark, and the other half at the same time intermittingly illuminated. Thus I could observe that almost the total sensitiveness of the whole plate resided in the granular coarse half of the surface. This shows that microphonic effects occur also in the selenium itself. But even if the selenium were perfectly homogeneous, and remained so during the illumination, the rays would produce heat and change of volume, which would have a microphonic influence on the contact.

By such microphonic changes the efficiency of the selenium cell would be explained, and thereby the selenium would be removed from its isolated position and coordinated with all the other bodies in which change of volume and of form under the influence of radiation have been observed.

I, however, do not deny that light may have other effects on the selenium. That such is the case is indeed one of the causes which have hitherto masked the microphonic action of the cells. That my present view of the simple action of the selenium did not present itself at once is owing to two causes.

In the first place, there is the fact that the microphonic variations or changes in volume and in form, attributed commonly to the so-called heat-rays, are produced in the selenium by the illuminating rays.

In the second place, complication is introduced by the fact that selenium exists in four allotropic modifications, and that light is able to exert on these divers influences. Though these are not essential to the action of the photophone, it has nevertheless been assumed by others, and at first by myself, that such changes might be the key for the explanation of the selenium photophone.

Of these two impediments which stood in the way of the perception of the microphonic action of the cells, I intend to speak more in detail. And first a few words on what, for the sake of brevity, may be called the heating effect of the light-rays.

In the beginning of April* I repeated the experiment of Mr. Graham Bell, and allowed light to pass through ebonite.

* Lond. Phys. Soc. April 9, 1881; 'Nature,' xxiii. p. 595.

In order to be able to make a quantitative observation I connected the selenium cell, on which the light was to fall, not only with the telephone, but also with a galvanometer. While, however, it appeared that a photophonic effect took place through the ebonite, it was shown that this effect was only a small part of the direct effect when the ebonite diaphragm was away. Now, as ebonite allows passage only to red and ultra-red rays, we learn from this experiment two things:—

(1) That the illuminating rays are those which are especially absorbed by selenium, and that these produce the greater part of the photophonic action.

(2) That it is even possible to make *a selenium photophone without light*—that is, with exclusion of illuminating rays and by the influence of heat-rays only.

That there is simply a heating effect of the illuminating rays in the selenium photophone has perhaps not yet been sufficiently insisted on, because the most modern researches on light-rays are not yet assimilated to the general view of physics. We find still the conception of three different kinds of rays—heating, illuminating, and actinic; whilst it has long been demonstrated that there is only one form of rays, differing from one another, however, in wave-length and intensity. On the body on which the ray falls depends whether its energy is perceived as heat, or light, or chemical effect. In order to be effective a ray must be absorbed. The bodies, however, on which the rays fall select the rays they absorb in the most various manner, which we recognize by the endless varieties of absorption-spectra. The absorbed rays alone are able to exert an effect; they only can warm the body. And heating occurs not only by red and ultra-red rays, but by the rays which are absorbed. Only the absorbed rays can produce (and that is the point in question here) changes of volume and of shape, and in this way influence the contact of current-conducting parts.

As the last-mentioned experiment demonstrates, selenium absorbs principally the illuminating rays. When, therefore. selenium is exposed to radiation, the change of volume and o shape is produced chiefly by the illuminating rays; *selenium is heated by light.* It must be the illuminating rays which make the selenium cell act microphonically.

That light, however, may produce in selenium other changes than heat and deformation, which are essential to the efficiency of the selenium cell, has been the second cause which masked the microphonic action of the cell. These are changes in the material; they concern rather the chemistry of selenium. They are indeed purely chemical if we view the existence of selenium in four allotropic modifications as a chemical quality. Into these chemical changes I shall enter here only so far as it is necessary for the proof that they are not essential to the microphonic action of the selenium cells, since my aim now is the physical one of correlating two forces.

When, now, we no longer consider the selenium cells especially, but selenium in general, we find that light can produce in it, if the selenium is an element and pure*, no other chemical changes than those which induce the transformation of one of the allotropic modifications into another one. But such a transformation is connected with development of energy; for in 1851 M. Hittorf† observed a rise of temperature of 90 degrees when the vitreous modification changed into the crystalline; and Regnault‡ (1856) in a similar case, observed an elevation of temperature of 130 degrees. With a proper arrangement (that is, in a closed circuit) we shall get, instead of the development of heat, an electric current—just as, for instance, two solutions of the same salt, but of different concentration, on being mixed together, give a development of heat, but, when brought into a circuit in a proper manner, produce electricity equivalent to this heat.

I have already mentioned above that Prof. W. G. Adams thus observed electromotive forces on illuminating selenium connected only with a galvanometer, but that generally the photophonic cells do not give such a development of electricity, and that therefore this property of selenium cannot be used

* On melting selenium, a grey film was formed on the surface. This being removed by a platinum spatula, the amorphous selenium showed a brilliant surface; and only such selenium was employed, in order to get congruent results.

Selenium crystals of 3 millim. length were obtained by sublimation on the cover of the crucible. At first amorphous selenium condensed; afterwards these sublimated crystals, which were insoluble in water, were formed.

† Pogg. *Ann.* lxxxiv. p. 216.

‡ *Ann. Chim. et Phys.* (3) xlvi. p. 284.

for the explanation of the efficiency of the photophonic cells. (Here I will add that of course thermoelectric currents can be produced by differential heating of the two junctions. In order to get such a great difference of heating, the cell must be exposed to greater heat. Thus I brought near the focus of the sun's rays only one small part of the cell, and found a small deflection of 10 divisions, or about half a centimetre.)

That by radiation the allotropic modification of selenium may be changed, but that such changes do not occur in the selenium cells, was proved most conclusively by one piece of selenium, which had the anomalous property of showing increased resistance on being illuminated.

Till now I had prepared all selenium cells and all pieces of selenium as I have described above, in the open air or in an air-bath. I never succeeded in obtaining selenium pieces of such low resistance as Messrs. Adams and Day got in three of their pieces, the resistances of which were 55, 58, 68 ohms. These three pieces differ, it is true, strongly from most of the other pieces in their resistances, which were as high as 7,600,000 ohms. I therefore followed their method almost literally. I laid several pieces of amorphous selenium, furnished with platinum electrodes and wrapped in paper, for twenty-four hours in sand which had been warmed before by a red-hot iron ball,—a process in which the influence of the aqueous vapour evolved from the paper is not excluded. In this way I got, indeed, pieces of the comparatively low resistance of 700 and 2000 ohms; whilst that of the other pieces prepared at the same time amounted still to 350,000 ohms.

The selenium piece of lowest resistance (700 ohms) showed at first so variable a resistance, that this could scarcely be measured. Then, when it became more constant, a determination of 700 ohms was possible. But on exposure to light, the resistance *increased.* This behaviour is just the opposite of what all my other cells or pieces of selenium show. And it is equally in contradiction to the diminishing of resistance found in all other cases by all other observers ; only Messrs. Adams and Day mention at the end of their numerous observations, that one single piece out of the great series behaved like this of mine, increasing its resistance on being illuminated. This piece of mine in which I observed this anomalous quality, exhibited in general the tendency to rise

steadily in resistance; so that there occurred, on illuminating it, a continuous increase of resistance, and, on darkening, a feeble but never a complete return to the original value. Every exposure to light again renewed this increase; and even a slight shaking of the table changed the resistance. This tendency to increase the resistance was manifested so strongly, that on the following day I found the resistance had risen from 700 to 5600 ohms.

But this piece of selenium showed still another anomaly, contributing, however, to the explanation of the first. I intended to examine the polarization produced in the selenium by the primary battery-current when separated from the battery and connected with the galvanometer by means of a switch. And now I found a secondary current which went through the galvanometer always in the same direction, quite independent of the direction of the primary battery-current. Even when the primary current was produced by a single Leclanché cell only, the deflection by the secondary current was 80 divisions, or about 5 centim. This secondary current is therefore no polarization-current; for in that ease its direction would be always opposite to the primary. But here a change of direction did not occur, the secondary current always flowing from the platinum electrode A to the platinum electrode B, and never in the opposite direction.

The passage of a current also, like illumination or concussion, occasioned a quicker increase of resistance.

All these qualities, however, are very easily understood; and the very appearance of the piece suggests the explanation. There are in it several modifications of the selenium side by side. At the transformation of the one modification into another, as I have pointed out above, heat or electric effect must take place. A state of equilibrium is not reached before that modification has been formed the formation of which is attended by the maximum development of energy—thermal or electric. Such modification again, as also mentioned above, has a different resistance from the one from which it originated; and therefore the variation of resistance is a necessary consequence of the change of modification. While the transformation goes on, we observe the electric current; after the transformation is complete we observe the change of resistance.

Such changes in the modification can be also occasioned by light: a pencil of amorphous selenium assumes, when exposed to the daylight, a grey crystalline surface.

Two conditions distinguish these changes from the photophonic ones, and prove that, as a rule, they do not occur in the photophonic cells.

On darkening the cell in which only a microphonic action took action, the original state was reached again which it had before being illuminated ; in the piece of selenium wherein a change of modification occurred, this was not the case. This is the reason why the light-spot returns to its original position on the galvanometer-scale in the case of the selenium cell, but does not in the case of the selenium piece. And, secondly, by such changes of modification a phenomenon is produced which has been called "fatigue." Such fatigue (that is, an insensitiveness) must take place as soon as the store of thè one modification which is transforming itself into the other is exhausted. But it cannot take place if we have to deal with a microphonic action alone. And, indeed, in the selenium cells I never could observe this fatigue. The sensitiveness of the last-described piece is now extremely lowered.

And thus we see that there are two different effects which light may have on selenium and on selenium cells. The one is more of a chemical, the other more of a physical character. The one is a changing of modification, and is not essential to the efficiency of the selenium photophone. In this latter we have to deal essentially with a heating effect, changing volume and contact—in brief, with a microphonic action.

Therefore, as to the photophonic efficiency of selenium, I see no reason to separate it from all other bodies ; and I no longer believe that there is any prospect of finding an unkown power or a new relation of forces in this substance.

The above experiments were performed in Prof. Guthrie's Physical Laboratory at the Science Schools, South Kensington. The permission granted me, at his request, by the Department of Science and Art to carry out my ideas experimentally is only one of the many acts of kindness and courtesy which I have received from scientific men and Societies during my sojourn in England.

Physical Laboratory, South Kensington,
June 1881.

XXXVII. *On Curves of Electromagnetic Induction.* *By* W. Grant*.

[Plates XV., XVI., & XVII.]

In the month of June 1879 I communicated to the Physical Society a series of measurements of the conjugate positions of two equal circular coils † of wire whose axes were parallel to each other—that is to say, measurements of the relative positions of the coils when they were so placed that their coefficient of mutual induction became nothing. I also showed how, by the aid of these measurements, a curve could be drawn such that when one coil remained fixed, and the other was moved with its centre always in the curve and its axis parallel to that of the first coil, the mutual induction between the coils retained the constant value zero. An obvious extension of this investigation was to try to trace out some of the curves of constant positive or negative induction lying on opposite sides of the curve of no induction; and it is the results of experiments made for this purpose, along with those of others which were made for the purpose of tracing some of the curves of constant induction between the coils with their axes perpendicular to each other, which I have now to bring before the Society.

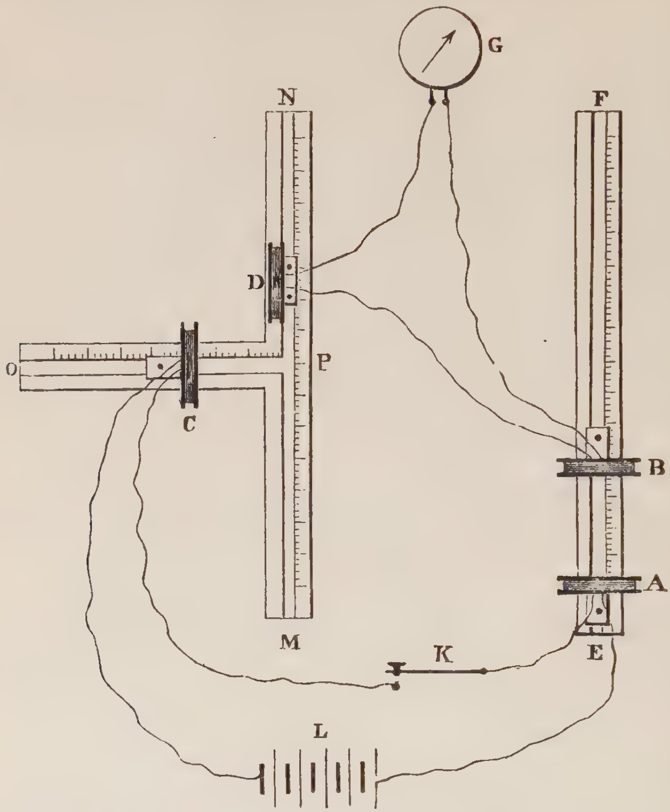
The arrangement of the apparatus and the nature of the experiments will be easily understood by reference to the annexed diagram.

A, B, C, and D are four coils of wire made as nearly identical in all respects as possible. Each coil consists of 182 turns of No. 24 silk-covered copper wire, of 0·065 centim. diameter, wound in a rectangular groove in a flat wooden reel. The inner circumferences of the coils are 21·95 centim.; their outer circumferences are 28·2 centim. The depth of the section of the coils perpendicular to the axis is 0·9947 centim.; the width of the groove parallel to the axis is 1·0 centim.: the section of the coils is therefore approximately one square centimetre. The mean radius is 3·99, or approximately 4·0

* Read June 11, 1881.

† Phil. Mag. for November, 1879.

centim. The resistances do not agree quite so closely; but their mean gives R=2·4 ohms at 11°·5 C.



The coils are mounted on straight guides which have grooves in their upper surfaces, along which the coils can be made to slide; and their positions are indicated by scales attached to the guides. The readings are obtained to centimetres and millimetres direct, and tenths of a millimetre by estimation. The coils A and B are mounted with their axes coincident on a straight guide E F, of sufficient length to allow their centres to be separated to a distance of 70 centimetres. The coils C and D are mounted on a pair of guides O P and M N, O P being about half the length of M N, and attached to it at right angles midway between its ends. The axes of the coils are parallel to O P and perpendicular to M N: hence

C can be moved parallel and D perpendicular to the axes without destroying the parallelism.

The coils A and C were connected with the battery L and with the key K to form the primary circuit; the coils B and D were connected with the galvanometer G, or sometimes with a telephone, to form the secondary circuit. Now it is evident that with this arrangement, in order that there may be no current in the secondary circuit on making and breaking the primary one, the coils C and D must be so placed that their mutual induction is equal to that between A and B; and, with reference to the secondary circuit, that the electromotive forces induced in the coils B and D must oppose each other. Hence, when A and B were clamped at a fixed distance apart, every pair of positions in which the coils C and D could be placed, so as not to cause a deflection of the galvanometer on making and breaking the primary circuit, were positions in which their mutual induction was constant, and determined one point of a curve of constant induction. Beginning with the coil D at P, the middle point of the guide M N, the coil C was moved until the induction between C and D balanced that between A and B. C was then moved nearer and nearer to P, being shifted a centimetre or so at a time; and the balance was restored in each case by moving D towards M or N. Now, as the arrangement is symmetrical with respect to the axis of C, it is evident that when a balance was obtained by displacing the coil D on one side of P, it could also be obtained by moving it to the corresponding position on the other side. In all cases these two balancing positions were found; and the half-difference of the readings on the scale M N, which was numbered from one end, was taken as the result of the experiment. In this way the measurements obtained were independent of any uncertainty in the determination of the point P. In using the numbers thus obtained for plotting a curve of constant induction, the distances read off along O P were taken as abscissæ, and the half-differences of the pairs of readings along M N were taken as ordinates. Thus in all the figures which accompany this paper, the axis of x is taken as coinciding with the axis of the primary coil with its centre fixed at the origin of coordinates, and the curves of constant induction are to be taken as representing

the paths traced out by the centre of the secondary coil in a plane containing the axes of x and y. The induced electromotive force changes sign when the centre of the secondary coil passes from one side to the other of the curve of no induction. In what follows, the induction is reckoned positive when the axes of the primary and secondary coils coincide. Hence, in the figures, all the curves lying between the axis of abscissæ and the zero-curve are to be taken as curves of positive induction; while those which lie further from the axis of abscissæ than the zero-curve are to be taken as curves of negative induction. The negative curves were traced experimentally in the same way as the positive curves, except that the two leading wires of one of the four coils were interchanged. Thus the inversion of electromotive force, due to the relative positions of the coils C and D, was counteracted by the inversion of the connections; and the inductive action between A and B could be balanced by that between C and D, just as in the measurements which gave the curves of positive induction.

The positive and negative divisions of the set of curves already alluded to, which, in what follows, are spoken of as the first set of curves, were each traced out with the apparatus arranged as in the diagram. But in order to trace out another set of curves, which are afterwards spoken of as the second set of curves, the axis of the coil D was set at right angles to that of C, but otherwise every thing remained unaltered. The zero-curve of the second set coincides with the axes of x and y; and therefore it did not require to be traced; each of the other curves is complete in one quadrant. The induced electromotive force changes sign when the centre of the coil D passes from one side to the other of the axes of x or of y: hence in the figures the second set of curves are to be taken as positive in one quadrant and negative in another alternately. The measurements for the second set of curves were made experimentally in the same way as for the first set; but as the axes of the coils C and D were at right angles, there was a considerable part of the field near the origin in which no measurements could be obtained, on account of the coils coming into contact with each other.

The positive or negative induction corresponding to any one

of the plotted curves being equal to that between A and B when placed at some definite distance from each other, it became necessary, in order to place the curves so that the numerical value of the induction-coefficient might have a known relative for each, to determine the law according to which the induction between the two coaxal coils A and B varied with the distance between them. For this purpose the coil A was connected with a contact-key and with a battery of 20 Grove's cells to form the primary circuit; the secondary circuit was formed by connecting the coil B with a contact-key and with the coils C and D, which were placed close together and used as a galvanometer. The needle and mirror employed were rather heavy: this had the advantage of allowing the induced currents to exert their full effect on the needle before it had moved perceptibly from its position of equilibrium. The key was a double-contact key, so arranged that on depressing the key the primary circuit was completed; and immediately afterwards, when the current was established, the secondary circuit, which was already complete, was opened, and was kept open by a spring acting on the lower key, while the primary circuit was then broken. The time occupied in depressing and releasing the key was in general about one third of a second; hence the time during which the primary current circulated every time that contact was made was approximately that period. With this arrangement only the induced current on making was allowed to act on the galvanometer, while that on breaking was prevented from circulating in the secondary circuit.

The temperature of the primary coil was indicated by a delicate thermometer divided to tenths of a degree Centigrade, which had its bulb placed in contact with the silk covering of the coil. The variation of the temperature of the coil, due to the heating effect of the current during the experiments (as indicated by this thermometer) was approximately $1^{\circ}\cdot 0$ C. The scale-readings obtained at the highest and lowest temperatures were found to agree so closely that it was unnecessary to make any correction on account of the variation of the temperature of the primary coil: its mean temperature during the experiments was $11^{\circ}\cdot 5$ C.

As the state of the battery was liable to change and the

strength of the current to vary, it was important that errors arising from these causes should as far as possible be eliminated. In order to effect this, a double set of observations was taken, first with increasing distances between the coils, and next with decreasing distances. In every position deflections were taken towards both ends of the scale; so that the recorded results represent the means of never less than four readings; and in most cases they are the means of twelve or sixteen. The observations were begun with the coils A and B as close together as possible without touching, and were continued till the distance between them was 70 centim.; but beyond about 50 centim. the galvanometer above mentioned, formed by the juxtaposition of the coils C and D, was not sufficiently sensitive. It was therefore replaced for these distances by a delicate reflecting galvanometer; and the necessary reduction was made after the ratio of the indications of the two instruments had been found. The deflections of the needle were indicated by the movements of a spot of light on a circular scale of one metre radius. The readings were obtained in centimetres and millimetres, and, after having been corrected for the effect of damping, were reduced to degrees. The value of the induced electromotive force, or, in other words, the strength of the induced current, was in each case taken as being proportional to the sine of half the angle through which the needle was deflected—that is, proportional to the sine of one fourth of the corrected scale-reading reduced to degrees. In using the numbers thus obtained for plotting a curve which graphically represents the values of the coefficient of mutual induction M for different distances of the coils A and B, the distances read off along the scale E F for the positions of the coil B were taken as abscissæ, and the values obtained for the sines were taken as ordinates. The results of these experiments are given in Table I., where the columns headed x give distances between the coils, and the columns z give the corresponding values of the coefficient of mutual induction. The curve plotted by means of these numbers is given in fig. 1, Plate XV.; the centres of the small circles in that and the following curves represent the points found in the experiments.

TABLE I.

Distance between centres of coils $=x$.	Relative value of induction-coefficient$=z$.	Distance between centres of coils $=x$.	Relative value of induction-coefficient$=z$.
centim.		centim.	
1·6	39·567	15·0	0·9
1·7	37·731	16·0	0·758
1·8	35·936	17·0	0·631
1·9	34·016	18·0	0·557
2·0	32·251	19·0	0·48
2·2	29·551	20·0	0·423
2·5	25·593	21·0	0·364
3·0	21·194	22·0	0·321
3·5	17·341	23·0	0·284
4·0	14·468	24·0	0·25
5·0	10·227	25·0	0·224
6·0	7·449	30·0	0·131
7·0	5·504	35·0	0·083
8·0	4·163	40·0	0·056
9·0	3·158	45·0	0·040
10·0	2·528	50·0	0·029
11·0	2·021	55·0	0·022
12·0	1·641	60·0	0·017
13·0	1·338	65·0	0·013
14·0	1·093	70·0	0·011

This curve is related to the curves of constant induction which form the main subject of this paper as the vertical section of a surface is related to the contour-lines of that surface. Imagine, then, a surface such that the three rectangular coordinates x, y, and z of any point upon it represent respectively the distance of that point from the centre of the primary coil, x being measured parallel to the axis of the coil, y perpendicular to it, and z being taken equal to M, the coefficient of mutual induction between the primary coil and the secondary coil placed with its centre at the point x, y, o. Then, the curve just described may be viewed as a section of this surface in a plane containing the axes of x and z, the curves of constant induction may be looked upon as contour-lines of the surface, or as sections of it in planes parallel to the plane of x and y, and the curve whose coefficient of mutual induction is equal in value to z will pass through the point in question.

The values of M, whether positive or negative, are synonymous with those of z: hence in the figures the curves of variable induction, which are situated in vertical planes, are

to be taken as positive if they are above the plane of x and y, and negative if they are below it. Where the values of the coordinates of any curve are represented in the Tables by x and y, the curve is situated in a horizontal plane; where they are represented by x and z, the curve is situated in a vertical plane. On examining the numbers in this Table, it appears that the values of z or M are approximately inversely proportional to the cube of the distance from the centre of one coil to the mean circumference of the other—that is, that the product Mc^3 is approximately constant, c being put for $\sqrt{a^2+x^2}$, where a is the mean radius of one of the coils. On closer examination it is seen that this product decreases somewhat from $x=0$ to about $x=a$, and then slowly increases for greater values of x.

By means of the curve (fig. 1, Plate XV.) it was easy to place the coils A and B so that their coefficient of mutual induction might have any desired value within the available range, and thus to assign determinate relative values to the coefficients of mutual induction corresponding to the curves to be traced out by the coils C and D. In Table II. the *first* and *fourth* columns give reference numbers referring to the several curves plotted in fig. 2, Pl. XVI., whose coordinates are given in Table III.; the *third* and *sixth* give the corresponding values of M, the coefficient of mutual induction; and the *second* and *fifth* the distance along the scale E F at which the coils A and B had to be clamped in order to obtain these values.

TABLE II.

No. of curve.	x.	M.	No. of curve.	x.	M.
1	0·5	Uncertain.			
2	1·0	Uncertain.			
3	2·025	32·0	13	31·6	− 0·125
4	3·72	16·0	14	24·0	− 0·25
5	5·78	8·0	15	18·7	− 0·5
6	8·15	4·0	16	14·45	− 1·0
7	11·05	2·0	17	11·05	− 2·0
8	14·45	1·0	18	8·15	− 4·0
9	18·7	0·5	19	5·78	− 8·0
10	24·0	0·25	20	3·72	−16·0
11	31·6	0·125	21	2·025	−32·0
12	......	Zero.			

The position on the scale E F, in which the coil B had to be placed in order to give the required value to the induction-coefficient of any curve, was found by inspecting Table II.; the coil was clamped in the position indicated; and a number of balancing pairs of positions of the coils C and D were then found.

In determining the values of the coordinates of the curve of zero induction the coils C and D only were employed. The primary circuit was the same as that in the diagram, omitting the coil A; the secondary circuit was also the same as that in the diagram, omitting the coil B. The coil C was brought as near as possible to the point P, and clamped in that position, sufficient room being left for the coil D to pass without touching it. D was then moved to a balancing position on one side of P, and then to the corresponding position on the other side of it, and the half-difference of the readings on the scale M N was taken as the value of the ordinate, the reading on the scale O P for the position of the coil C during the experiment being taken as the value of the corresponding abscissa.

The least distance between the centres of the coils C and D at which readings could be obtained when their axes were coincident was 1·6 centimetre, as their thickness prevented a nearer approach; the least distance between their axes at which readings could be obtained, when the mean planes of the coils were coincident or at a less distance than 1·6 centim. from each other, was about 9·2 centim. There was, therefore, in each quadrant a rectangular area of which these dimensions are the sides within which no results could be obtained.

In order to extend the experimental curves within this area, two coils, whose centres could be brought within 2 millim. of one another, were constructed from the remainder of the piece of wire from which the other four were made. Their diameters were approximately the same as those of the other coils; but, owing to their thinness and the consequent small number of convolutions of wire, their coefficient of mutual induction was much less; but this defect was compensated to some extent by their proximity. The lines of force due to them were slightly different in form from those due to the thick coils; but as in

most positions of the thin secondary coil the lines of force passed through it nearly at right angles, there was less objection to the use of the thin coils than if they had been at a greater distance apart. They were fitted one to each of the coils C and D, so that the same mountings served for both, and the readings were obtained from the same scales. That which was fitted to the former we shall call C_0, that which was fitted to the latter we shall call D_0.

In continuing the measurements within the area already mentioned, the coils C_0 and D_0 were placed in the same balancing pair of positions which C and D had occupied when the last point of a given positive curve was determined. The coil B was then moved towards F along the guide E F to a position in which the mutual induction between A and B balanced that between C_0 and D_0; this gave the desired value to the induction-coefficient of the curve; and the remaining points were found as in previous cases. Without again shifting the coil B, a negative curve, the induction-coefficient of which had the same relative value as that of the positive curve, could either be continued or completely traced out by interchanging the leading wires of the coil D_0 and passing it to the negative region. Thus the curves, whether positive or negative, could either be continued or completely traced out with the thin coils just as with the thick ones; and a constant value could be given to the mutual induction between the coils C_0 and D_0 in each pair of balancing positions, proportional to, although not the same as the value assigned to M for a given curve. Hence the path traced out by the centre of the coil D_0 was practically the same as that which would have been followed by the centre of the coil D, had it been possible to use it in tracing the same curve in that part of the field. The value of the induction-coefficient of each of the two curves nearest to the origin is uncertain, as the value of z which corresponds to that of x for either of these curves is beyond the range of the curve, fig. 1. A convenient, although uncertain value was given to the induction-coefficient of either of these curves by placing D_0 at the point P and moving C_0 towards O until the distance between the centres of C_0 and D_0 was equal to that between the origin and the point where the

curve was required to cross the axis of x, then balancing by the coil B and finding the remaining points of the curve. In completing several of these curves for which the value of M was comparatively small, it was found that the mutual induction between A and B was greater than that between C_0 and D_0, even when B was placed at the extreme end of the scale E F. Hence, in order to reduce it in such cases, B was laid down flat on the guide and displaced towards E or F until a balance was obtained; and although the value of the induction-coefficient was uncertain, the mutual induction between A and B was equal to that between C_0 and D_0 when they occupied a balancing pair of positions previously occupied by C and D, and remained constant while A and B retained the same relative positions.

The coordinates of the first set of curves of constant induction are given in Table III., and are numbered in accordance with Table II.

The results obtained by means of the thin coils C_0 and D_0 are distinguished in the Table by being enclosed in square brackets [ ].

Table III.

Curve 1, M uncertain.		Curve 2, M uncertain.	
x.	*y*.	*x*.	*y*.
[0·2]	[0·97]	[0·2]	[1·77]
[0·3]	[0·81]	[0·5]	[1·43]
[0·4]	[0·58]	[0·7]	[1·14]
[0·5]	[0·0]	[0·9]	[0·67]
		[1·0]	[0·0]
Curve 3, M = 32.		**Curve 4, M = 16.**	
[0·2]	[3·06]	[0·2]	[4·35]
[1·0]	[2·4]	[1·0]	[4·07]
1·6	1·59	1·6	3·74
1·9	0·88	2·0	3·46
2·025	0·0	3·0	2·37
		3·5	1·35
		3·72	0·0
Curve 5, M = 8.		**Curve 6, M = 4.**	
[0·2]	[5·17]	[0·2]	[5·65]
[1·0]	[5·07]	[1·0]	[5·69]
1·6	4·985	1·6	5·695
2·0	4·885	2·0	5·705
3·0	4·505	3·0	5·68
4·0	3·855	4·0	5·5
5·0	2·705	5·0	5·15
5·5	1·66	6·0	4·53
5·78	0·0	7·0	3·5
		7·5	2·69
		8·0	1·345
		8·15	0·0
Curve 7, M = 2.		**Curve 8, M = 1.**	
[0·2]	[5·89]	[0·2]	[6·0]
[1·0]	[6·0]	[1·0]	[6·15]
1·6	6·105	1·6	6·325
2·0	6·195	2·0	6·475
3·0	6·43	3·0	6·89
4·0	6·585	4·0	7·28
6·0	6·495	6·0	7·84
8·0	5·69	8·0	7·84
9·0	4·935	10·0	7·25
10·0	3·685	12·0	5·925
10·5	2·73	13·0	4·685
10·8	1·8	14·0	2·885
11·05	0·0	14·3	1·555
		14·45	0·0

Table III. (*continued*).

Curve 9, M=0·5.		Curve 10, M=0·25.	
x.	*y*.	*x*.	*y*.
[0·2]	[6·07]	[0·2]	[6·12]
[1·0]	[6·24]	[1·0]	[6·29]
1·6	6·445	1·6	6·515
2·0	6·63	2·0	6·715
3·0	7·18	3·0	7·325
4·0	7·745	4·0	8·04
6·0	8·79	6·0	9·475
8·0	9·435	8·0	10·66
10·0	9·61	10·0	11·465
12·0	9·33	12·0	11·845
14·0	8·455	14·0	11·825
16·0	6·845	16·0	11·45
17·0	5·55	18·0	10·56
18·0	3·49	19·0	9·9
18·5	1·8	20·0	9·05
18·7	0·0	21·0	8·05
		22·0	6·775
		23·0	4·85
		23·5	3·2
		23·8	1·74
		24·0	0·0

Curve 11, M=0·125.			
[0·2]	[6·14]	20·0	15·0
[1·0]	[6·32]	22·0	14·45
1·6	6·545	24·0	13·55
2·0	6·76	25·5	12·525
3·0	7·42	27·0	11·175
4·0	8·215	28·0	10·05
6·0	9·965	29·0	8·725
8·0	11·635	30·0	6·83
10·0	13·025	30·5	5·5
12·0	14·075	31·0	3·95
14·0	14·82	31·4	2·05
16·0	15·2	31·6	0·0
18·0	15·2		

Curve 12, M=zero.			
[0·2]	[6·15]	12·0	18·055
[1·0]	[6·35]	13·0	19·45
1·6	6·575	14·0	20·775
2·0	6·8	15·0	22·15
2·5	7·135	16·0	23·54
3·0	7·5	17·0	24·9
4·0	8·38	18·0	26·275
5·0	9·395	19·0	27·65
6·0	10·505	20·0	29·0
7·0	11·675	21·0	30·376
8·0	12·89	22·0	31·775
9·0	14·115	23·0	33·13
10·0	15·4	24·0	34·5
11·0	16·745		

Table III. (*continued*).

Curve 13, M = −0·125.			Curve 14, M = −0·25.		
x.	*y*.	*y'*.	*x*.	*y*.	*y'*.
0	......	26·0	0	......	20·22
[0·2]	[6·16]	......	[0·2]	[6·18]	......
[1·0]	[6·38]	25·97	[1·0]	[6·42]	20·105
1·6	6·615	25·86	1·6	6·64	19·97
2·0	6·845	25·81	2·0	6·89	19·83
3·0	7·6	25·5	3·0	7·72	19·35
4·0	8·58	25·0	4·0	8·855	18·56
5·0	9·795	24·35	5·0	10·475	17·365
6·0	11·275	23·4	5·7	12·4	15·75
7·0	13·33	21·95	5·9	14·05	14·05
7·7	15·325	19·95			
8·0	18·05	18·05			

Curve 15, M = −0·5.			Curve 16, M = −1·0.		
0	......	16·27	0	......	13·305
[0·2]	[6·2]	......	[0·2]	[6·24]	......
[1·0]	[6·48]	16·21	[1·0]	[6·56]	13·125
1·6	6·725	15·975	1·6	6·865	12·85
2·0	7·0	15·79	2·0	7·195	12·6
3·0	7·96	15·09	3·0	8·73	11·27
4·0	9·62	13·74	3·2	9·49	10·605
4·4	11·9	12·33			

Curve 17, M = −2·0.			Curve 18, M = −4·0.		
0	......	11·085	0	......	9·445
[0·2]	[6·35]	......	[0·2]	[6·64]	......
[1·0]	[6·7]	10·835	[0·5]	[6·81]	9·33
1·6	7·215	10·4	[0·7]	[7·02]	9·225
2·0	7·825	9·845	[1·0]	[7·445]	[8·85]
2·2	8·48	9·18	[1·2]	[8·15]	[8·15]

Curve 19, M = −8·0.			Curve 20, M = −16·0.		
[0·2]	[7·165]	[8·42]	0	7·45	8·0
[0·3]	[7.33]	[8·29]	0·1	7·52	7·95
[0·4]	[7·6]	[8·02]	0·15	7·7	7·83

Point of maximum negative intensity, No. 21, M = −32·0.	
x.	*y*.
0	7·7

The first set of curves of constant induction are given in fig. 2, Plate XVI. Curve 20 and the point of maximum negative induction could not be found experimentally; they are therefore only given as near approximations. The rectangular space near the origin shows the region within which the auxiliary coils C_0 and D_0 (see p. 369) had to be employed. These curves represent the contour-lines of one quadrant of the surface above described, and show at what distance from the origin any curve cuts the axis of y. Knowing this, and knowing also the relative value of M or of z for each curve, we obtain a set of values for the coordinates of a curve which may be viewed as a section of the surface in question in a plane containing the axes of y and z. These coordinates are given in Table IV.; the curve plotted by means of them is given in fig. 3, Pl. XVII.; but the dotted part of it is only approximate.

TABLE IV.

y.	z.	y.	y'.	z.
2·6	39·55	6·15	26·0	− 0·125
3·07	32·0	6·17	20·22	− 0·25
4·38	16·0	6·19	16·27	− 0·5
5·18	8·0	6·23	13·305	− 1·0
5·64	4·0	6·33	11·085	− 2·0
5·88	2·0	6·58	9·44	− 4·0
5·99	1·0	7·02	8·48	− 8·0
6·06	0·5	7·45	8·0	−16·0
6·11	0·25	7·7	7·7	−32·0
6·13	0·125			
6·14	0·0			

In order to give a better idea of the symmetry of the curves of constant induction than can be got from fig. 2, the curves in that figure have been repeated in the other quadrants, and are given in fig. 4, Pl. XVII., for the whole of the magnetic field of the primary coil. Now every thing is symmetrical relatively to the axis of x, and each curve represents a section of a surface of revolution about that axis. Hence, if the curves are supposed to revolve round the axis of x, a number of surfaces of revolution will be generated, each of which will be a surface of constant induction, the surfaces of positive induction being separated from those of negative induction by the surface of no induction. The positive surfaces may be described as shells which enclose one another, and each of which turns inwards, closing up round the axis of x on each side of the origin. The zero-surface, which divides the positive from the

negative surfaces, instead of closing up, may be supposed to extend in space to an infinite distance. The negative surfaces turn outwards and close up in a plane containing the axes of x and z; they are hollow circular rings which enclose one another, and which have their common centre at the origin of coordinates.

In the series of measurements for the determination of the second set of curves, the axis of the coil D was perpendicular to that of C, but otherwise every thing was arranged as in the diagram. The same values were given to M for these curves as for the others, by setting the coil B in the same positions on the scale E F which it had occupied during the previous experiments. These curves are numbered in accordance with Table V.

TABLE V.

Number of curve.	x.	M.
1	31·6	0·125
2	24·0	0·25
3	18·7	0·5
4	14·45	1·0
5	11·05	2·0
6	8·15	4·0

The zero-curve of this set coincides with the axes of coordinates; and, in general, when two similar coils with their axes perpendicular are employed, one as primary and the other as secondary, their mutual induction is zero when the axis of the one lies in the mean plane of the other. This shows that any curve of the second set for which the value of M is small must make a near approach to the axes of coordinates in the neighbourhood of the origin, and that a part of each curve in that region cannot be traced experimentally with the coils employed. The coordinates of these curves, as far as it was found possible to determine them experimentally, are given in Table VI.; but there is with this set a larger space near the origin within which the dimensions of the coils made it impossible to get measurements than was the case with the first set of curves. In the figures, the curves are continued conjecturally within this space by dotted lines. The second set of curves are given in fig. 5, Pl. XVI.

TABLE VI.

Curve 1, M=0·125.					
x.	y.	y'.	x.	y.	y'.
0·06	......	5·02	5·5	0·05	21·88
0·1	......	7·1	6·0	0·05	22·22
0·2	......	9·26	8·0	0·12	23·3
0·3	......	10·45	10·0	0·23	23·85
0·4	......	11·34	12·0	0·47	24·15
0·5	......	12·1	14·0	0·84	23·97
0·7	......	13·3	16·0	1·35	23·49
1·0	......	14·54	18·0	2·3	22·57
1·5	......	16·2	20·0	3·67	21·1
2·0	......	17·37	22·0	5·72	18·9
3·0	......	19·18	23·0	7·29	17·05
4·0	......	20·48	24·0	10·25	13·48
5·0	......	21·42			

Curve 2, M=0·25.					
x.	y.	y'.	x.	y.	y'.
0·1	......	5·09	5·0	......	17·26
0·2	......	7·18	5·5	0·1	17·54
0·3	......	8·28	6·0	0·11	17·77
0·4	......	9·16	8·0	0·24	18·36
0·5	......	9·77	10·0	0·53	18·45
0·7	......	10·74	12·0	1·03	18·02
1·0	......	11·82	14·0	1·9	17·1
1·5	......	13·13	16·0	3·44	15·45
2·0	......	14·13	17·0	4·55	14·22
3·0	......	15·55	18·0	6·51	12·27
4·0	......	16·54	18·4	8·0	10·4

Curve 3, M=0·5.			Curve 4, M=1·0.		
x.	y.	y'.	x.	y.	y'.
0·21	......	5·4	0·4	......	5·42
0·3	......	6·4	0·5	......	6·1
0·4	......	7·24	0·7	......	7·02
0·5	......	7·84	1·0	......	7·92
0·7	......	8·72	1·5	......	8·89
1·0	......	9·72	2·0	......	9·57
1·5	......	10·88	3·0	......	10·52
2·0	......	11·65	4·0	......	11·06
3·0	......	12·82	5·5	0·39	......
4·0	......	13·59	6·0	0·46	11·46
5·0	0·17	14·1	8·0	1·01	11·04
5·5	0·19	14·28	10·0	2·33	9·64
6·0	0·23	14·38	11·0	3·85	8·11
8·0	0·5	14·54	11·4	5·0	6·9
10·0	1·07	14·06			
12·0	2·19	12·87			
13·0	3·17	11·82			
14·0	4·69	10·17			
14·5	6·34	8·35			

Table VI. (*continued*).

Curve 5, M=2.			Curve 6, M=4.		
x.	y.	y'.	x.	y.	y'.
0·8	......	5·54	1·6	......	5·5
1·0	......	6·17	1·8	......	5·76
1·6	......	7·27	2·0	......	6·0
2·0	......	7·76	2·5	......	6·45
3·0	......	8·54	3·0	......	6·72
4·0	......	8·91	4·0	......	6·96
5·0	......	9·0	5·0	......	6·82
5·2	0·69	......	5·5	1·55	6·66
6·0	0·92	8·85	6·0	1·9	6·31
7·0	1·37	8·41	6·5	2·45	5·78
8·0	2·23	7·58	7·0	3·62	4·61
9·0	4·13	5·56			

The positive and negative curves of the second set have the same form, and are positive in one quadrant and negative in another alternately. They have been treated as an independent set of curves; but, as will afterwards appear, they are not so, but are merely a special case in which the positive curves of the first set have become separated by the intervening zero-curve which coincides with the axes of x and y. In this case any corresponding pair of positive and negative curves, besides having the same form, have also the same linear dimensions. In every other case the form and linear dimensions of any corresponding pair of positive and negative curves are different, the linear dimension of the negative curve being always less than that of the positive. Hence this is the case in which the linear dimension of any negative curve is greatest, and in which that of the corresponding positive curve is least. The second set of curves, for the whole of the magnetic field, are given in fig. 6, Pl. XV., which shows the relative positions occupied by them in the various quadrants.

When a system of curves of constant induction have been obtained for a given pair of coils, they may be used to give the total inductive effect produced on one of the coils by a given change of relative position while the other coil is traversed by a current of known strength. To simplify the statement, suppose the primary coil in which there is a current of uniform strength C to remain at rest while the secondary coil is moved from a position such that the coefficient of mutual

induction is M_1, to a position in which this coefficient becomes M_2. Then, if t is the time occupied by the movement, the average electromotive force e which acts in the secondary circuit during the movement is

$$e=\frac{M_2-M_1}{t}C;$$

and if r be the resistance of the secondary circuit, the average strength of the secondary current is

$$c=\frac{e}{r}=\frac{M_2-M_1}{rt}C.$$

The total quantity, q, of electricity conveyed by the secondary current is consequently

$$q=ct=\frac{M_2-M_1}{r}C,$$

and is therefore independent of the time occupied in the displacement of the secondary coil.

The values of M_1 and M_2, the coefficients of induction corresponding to the initial and final positions of the secondary coil, can be obtained by inspection of diagrams of curves of constant induction such as those which accompany this paper. It is evident that the total secondary current is nothing in every case in which the secondary coil is moved so as to make $M_2=M_1$ (that is, whenever the secondary coil in its final position is on the same curve as in its first position), and that the secondary current is positive when the absolute value of M_2 is greater than that of M_1, and negative when M_2 is less than M_1.

The spaces between the curves in the figures may be filled up as follows by other curves, for which the values of M lie within the available range of the curve fig. 1. Assume a value for M which will lie between its values for two curves already drawn; take this as the value of z, and find the point of the curve fig. 1 to which it corresponds. A point on the axis of x will thus be found, which will divide the distance between the two points on that axis, whose values are those of x for the given curves, into two parts whose ratio may easily be found. Then, if a series of points between the two given curves are found for which this ratio is constant, a curve joining these points will be a curve of constant induction, for which the value of M will be that which was assumed.

The curves of constant induction may also be employed in a graphic method for determining, at a number of points in the magnetic field, the direction of the resultant inductive effect on the secondary coil in the positions in which it was used in the measurements for determining the two sets of curves. If the curves figs. 2 and 5 are superposed as in fig. 7, Pl. XVI., we may resolve by the parallelogram of forces at a number of points where the curves intersect. For this purpose components are taken whose values are proportional to the values of M for the curves, and, from the point where any two curves intersect, lines are drawn proportional to these values for the two intersecting curves. The component which is proportional to the value of M for the curve of the first set is drawn parallel to the axis of x; and that for the curve of the second set is drawn at right angles to it. Compounding, we then obtain as resultant a straight line proportional to the magnitude, and in the direction, of the resultant inductive effect on the secondary coil in two positions at right angles to each other. The arrows at the points of intersection of the curves in fig. 7 show the directions of these resultants. If the curves had been obtained by means of an indefinitely small secondary coil, the resultants would have been tangents to the lines of force, and the straight lines drawn through the same points at right angles to the resultants would have been tangents to the equipotential curves; but with the coils employed this is not strictly the case.

The two sets of curves in the figures are so related to one another that the one set may be viewed as a modified form of the other. If we begin with the axes of the primary and secondary coils parallel, and gradually increase the angle between them, the curves of maximum induction, as it were, carry the curves of constant induction round with them, while the curves of zero induction, in moving round, always form lines of demarcation which separate the positive from the negative regions. The positive curves of constant induction at the same time become distorted and gradually contract, the linear dimensions of each curve becoming less until the angle between the axes is about 90°. When this angle has become exactly 90°, the positive curves of constant induction have become separated into two distinct divisions by the intervening zero-curve (which coincides with the axes

of x and y), so that they then occupy two opposite quadrants. Now, both the positive and the negative curves move round together; but as the negative curves are carried round they become distorted and gradually expand, the linear dimensions of each curve becoming greater until the angle between the axes of the coils is 90°. When this, which is the extreme or limiting case, has been reached, the form and linear dimensions of any negative curve are the same as those of either of the two corresponding positive curves for which the value of M is the same, and the two sets of negative curves, which originally were each bisected by the axis of y, have then come to occupy the two remaining opposite quadrants. Thus the one set of curves of constant induction merges into the other, and the forms of both sets, which may be described as ovals, depend upon the angle between the axes of the primary and secondary coils.

We see, then, that the second set of curves, although found experimentally, are not entirely independent of the first set, and that being positive and negative in alternate quadrants, they have no corresponding surfaces of revolution, that the only curves of constant induction which have corresponding surfaces of revolution are those which are obtained when the axes of the primary and secondary coils are parallel, and that all curves of constant induction which are due to the coils when their axes make any other angle with each other are merely modified forms of them.

The arrangement of apparatus employed in this investigation, namely two similar coils in the primary and two other similar coils in the secondary circuit, was employed by Dove in his researches, and was called by him the "Differential Inductor" (*Annales de Chimie et de Physique*, tome iv. 1842).

The same arrangement was employed by Felici, a short account of whose researches is given in Maxwell's 'Electricity and Magnetism,' vol. ii. pp. 169–172.

In conclusion, my special thanks are due to Prof. G. C. Foster, for the general interest which he has taken in this subject, and for many important suggestions made during the progress of the investigation.

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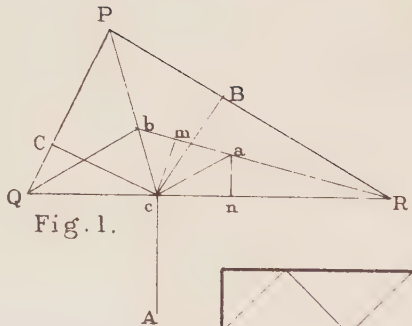


Fig. 1.

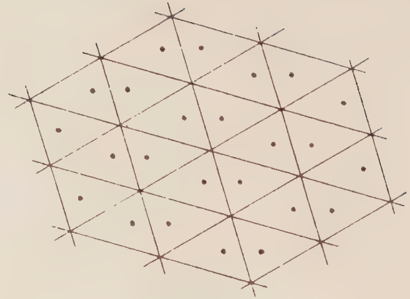
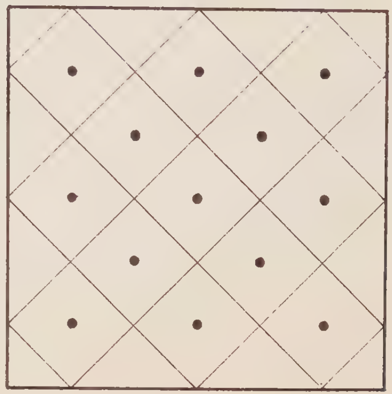
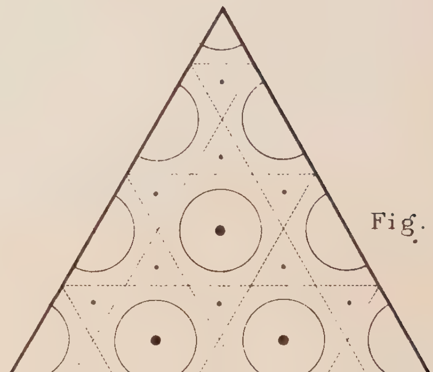


Fig. 2.

Fig. 3.

Fig. 5.
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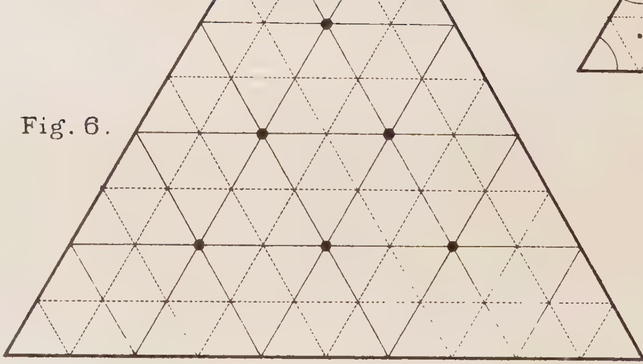

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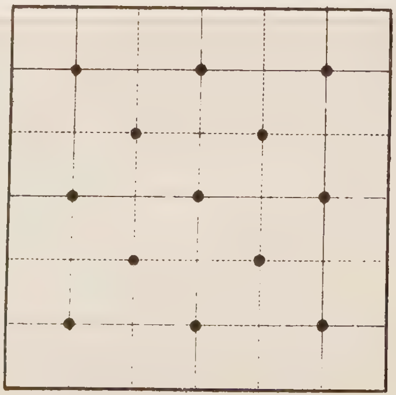


Fig. 7.

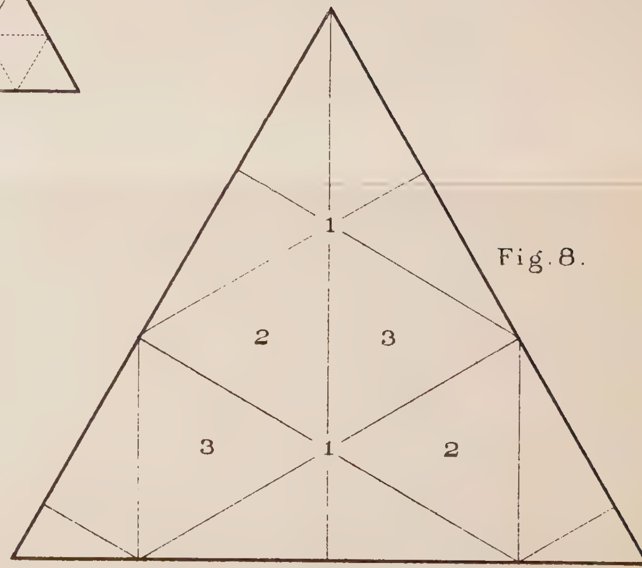
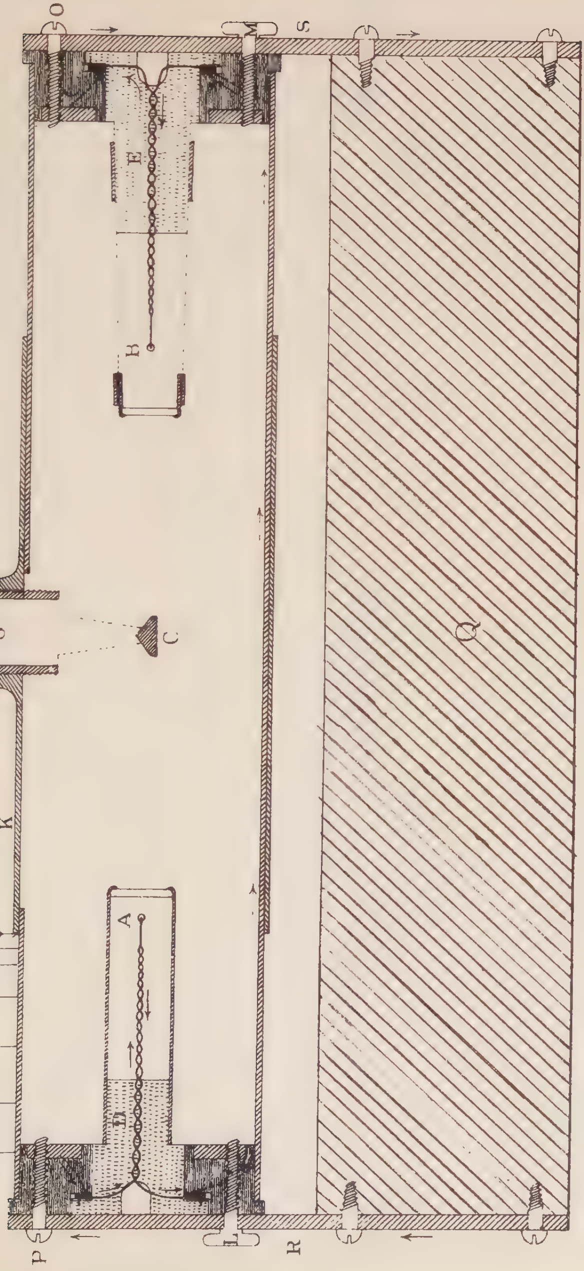
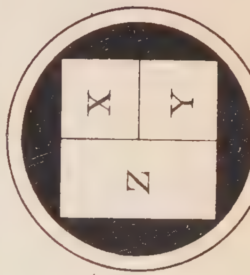


Fig. 8.

Gas Indicator. Longitudinal section.





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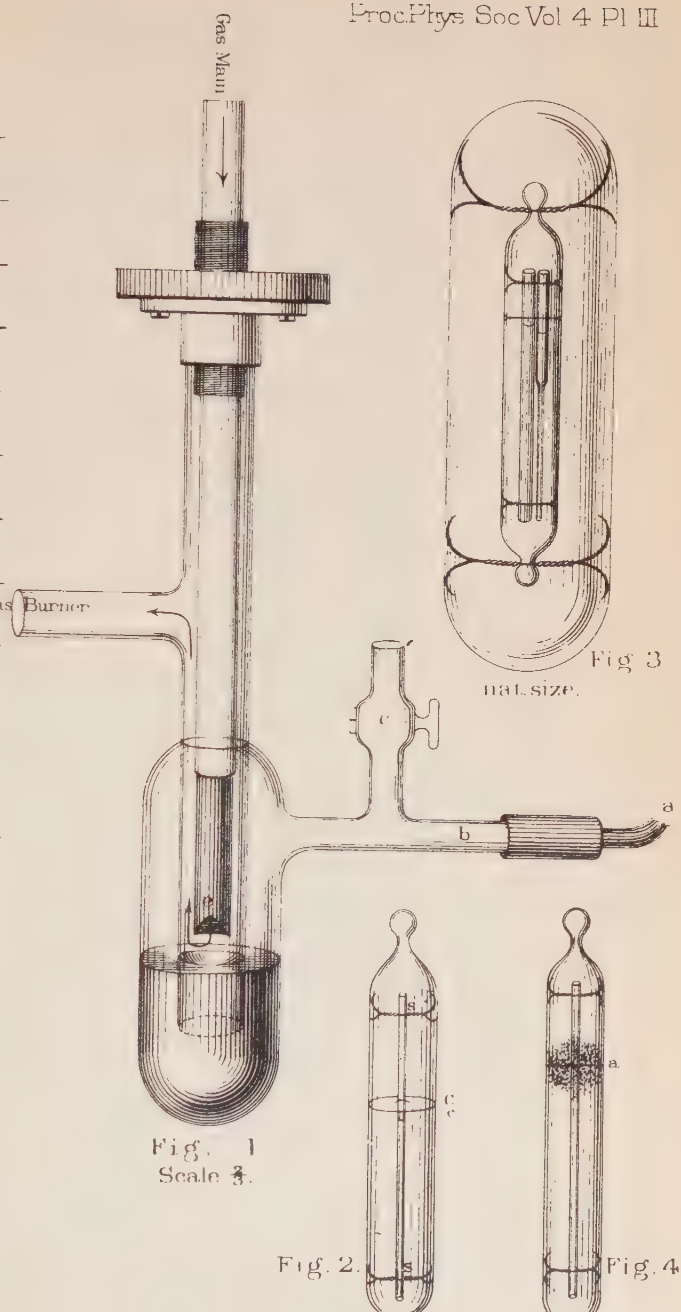

Fig. 1
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Fig 3
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Fig. 2.
nat. size

Fig. 4
nat. size.

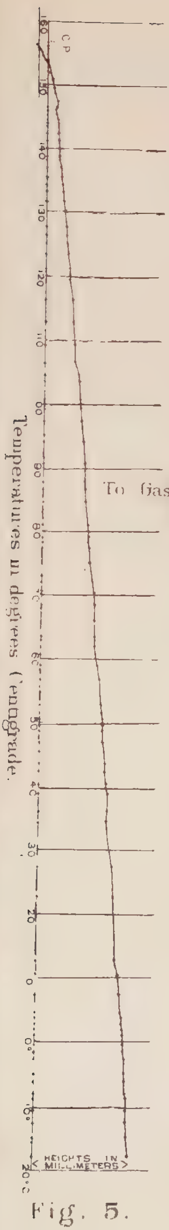
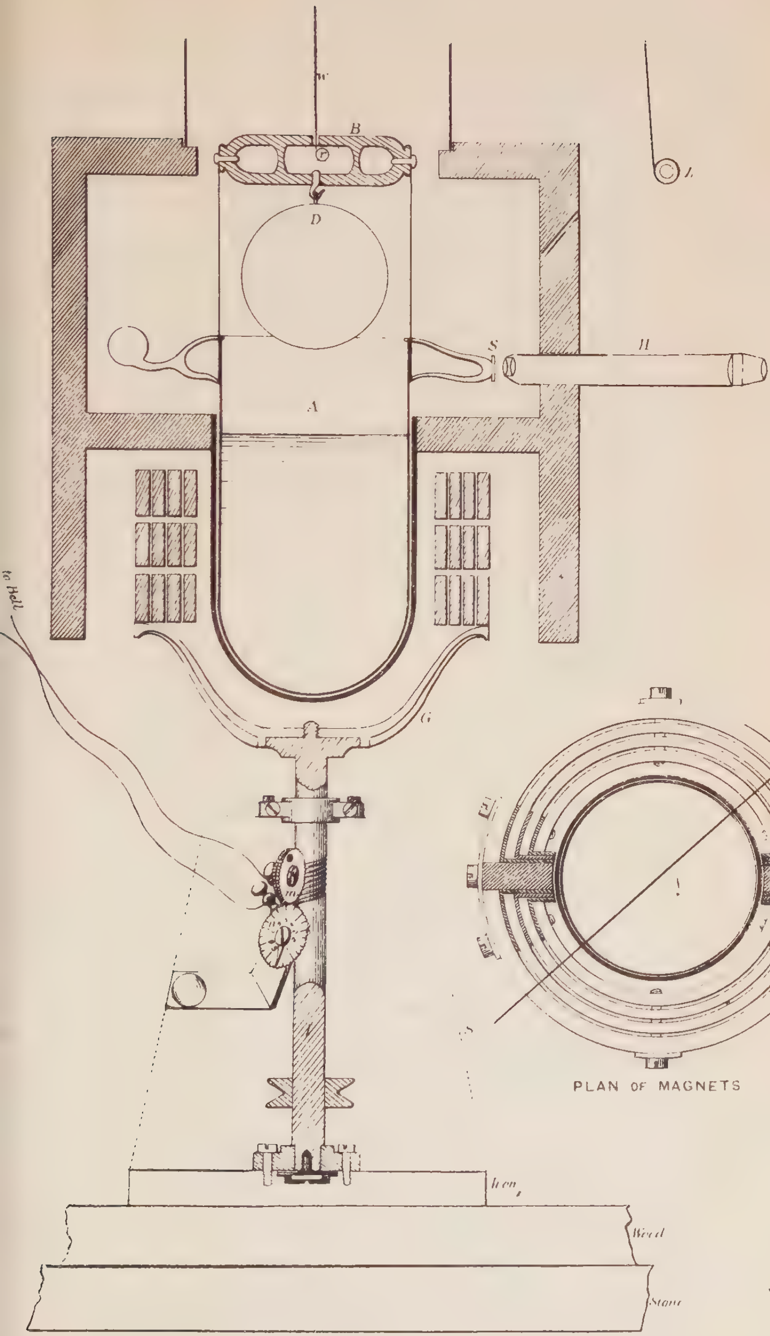
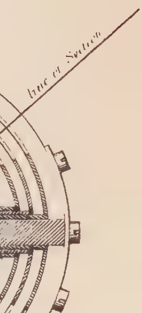


Fig. 5.





PLAN OF MAGNETS

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Fig 1
Air Thermometer

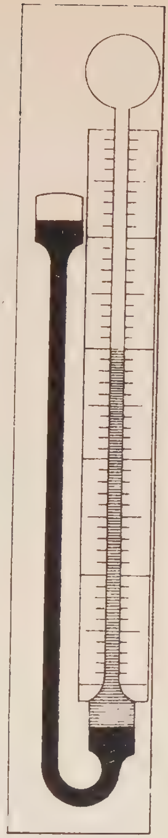

Fig 2.
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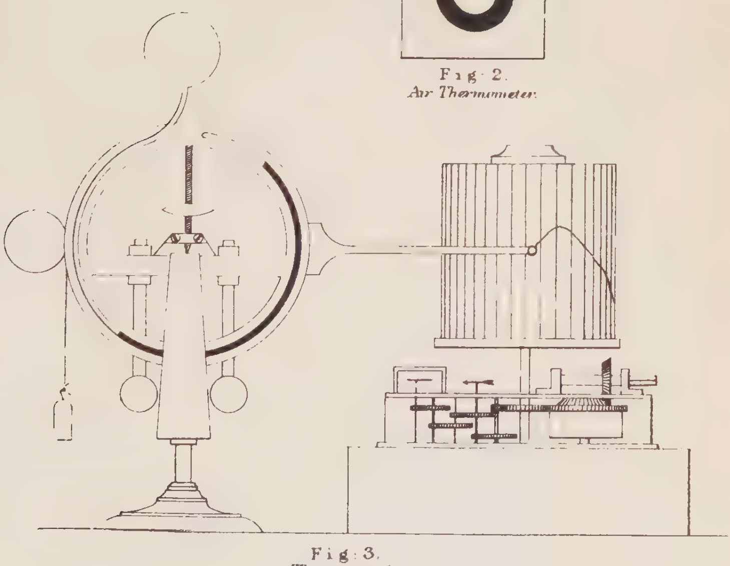

Fig: 3.
Thermograph.

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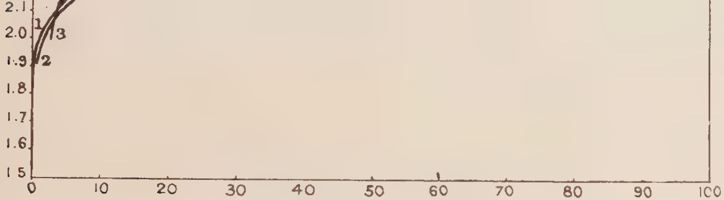

Fig: 3

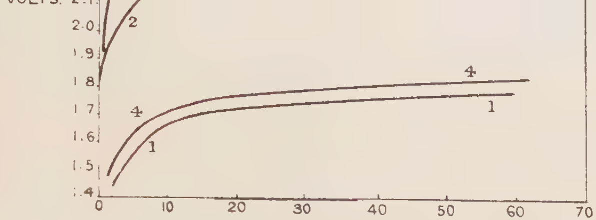

Fig: 5.

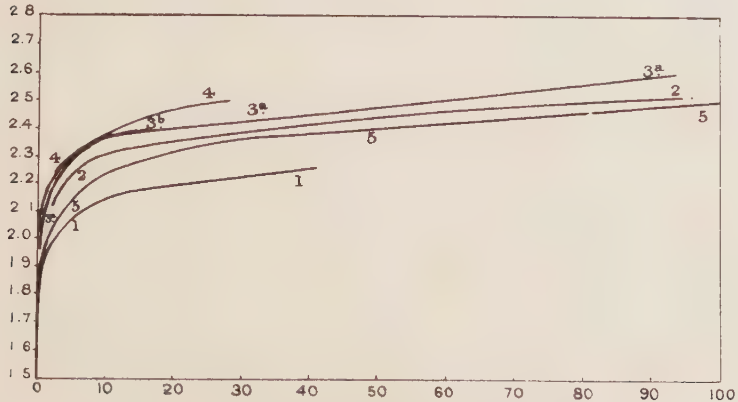

Fig: 4.

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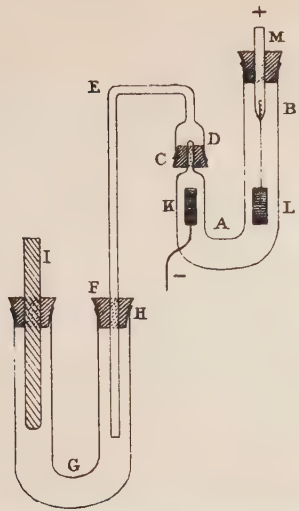

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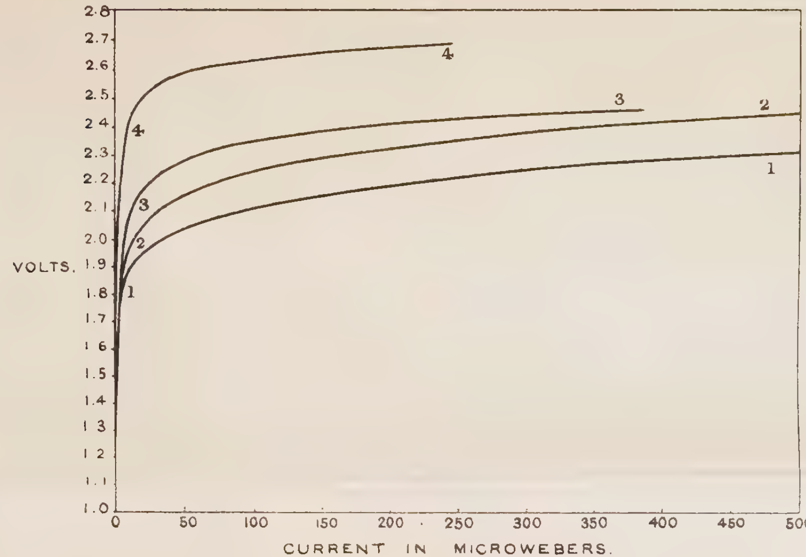

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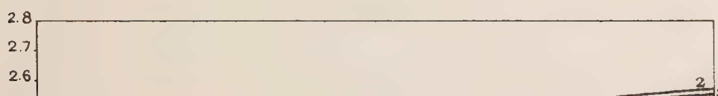

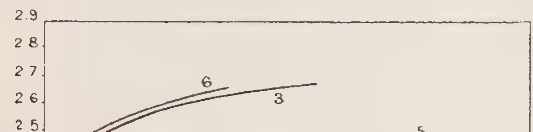


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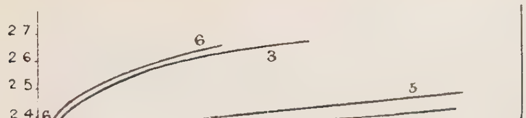
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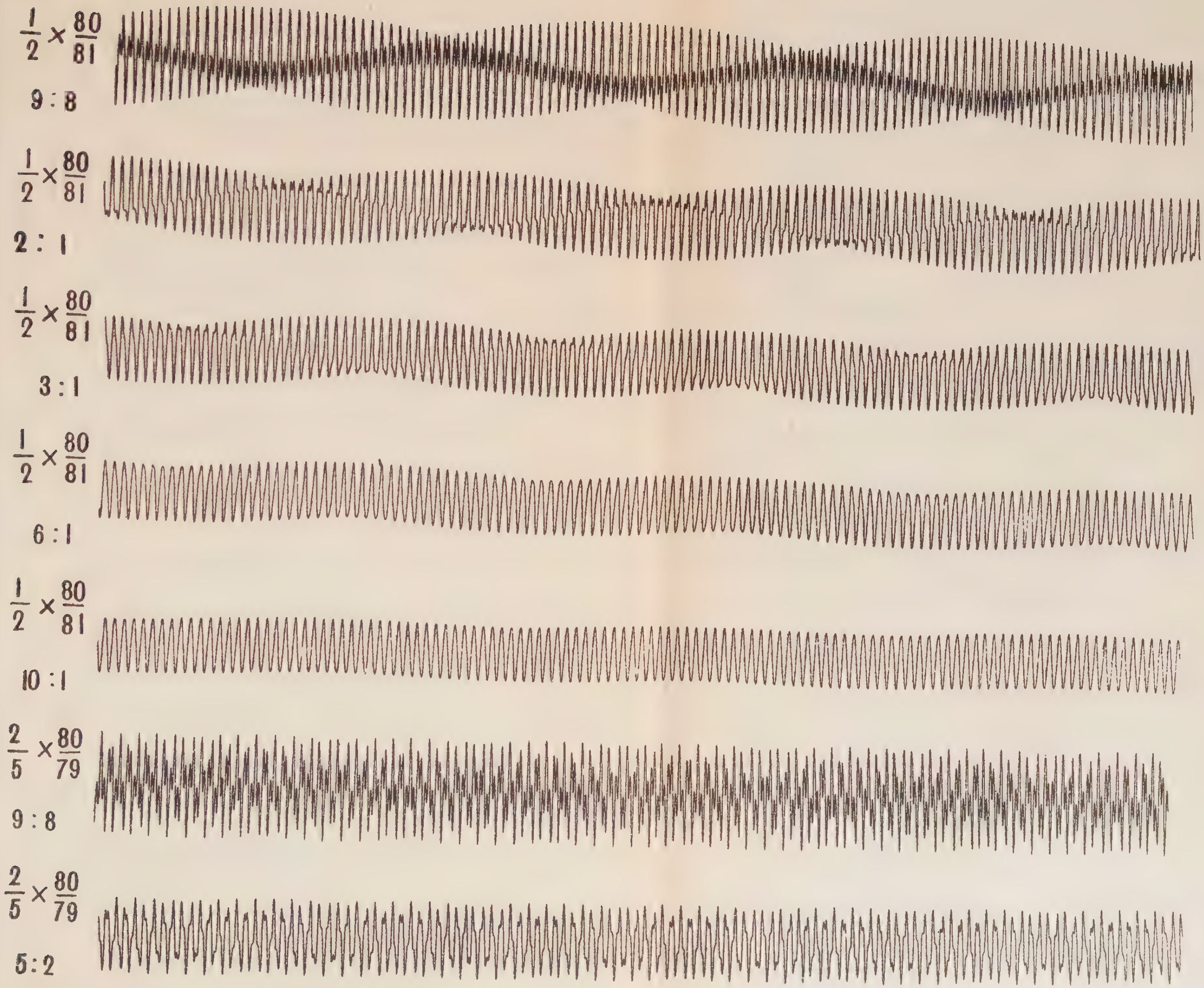
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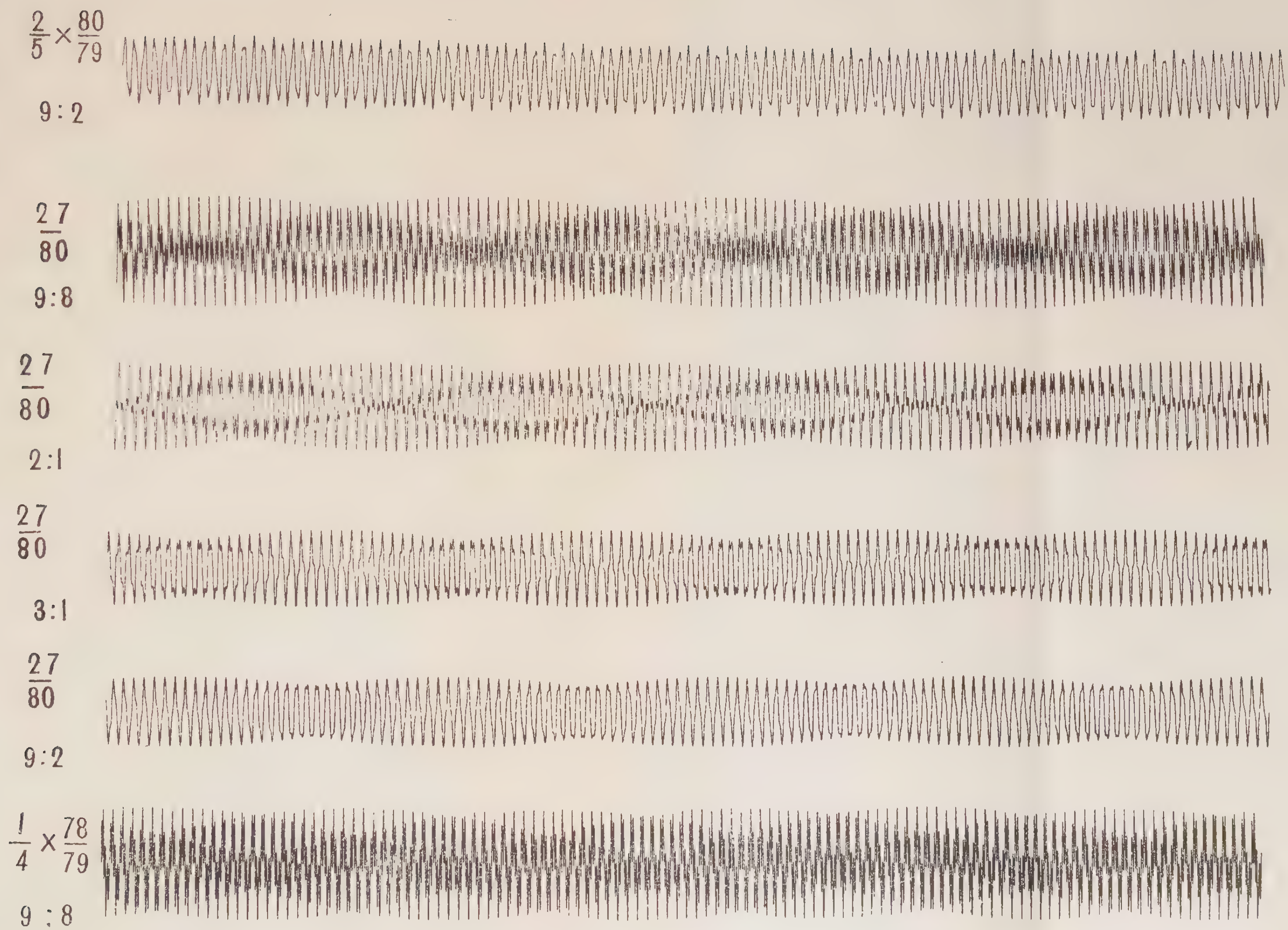

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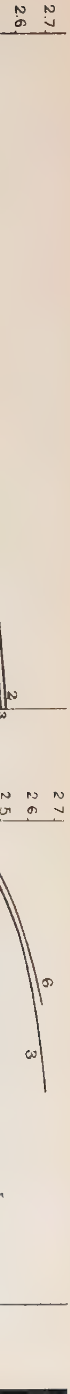

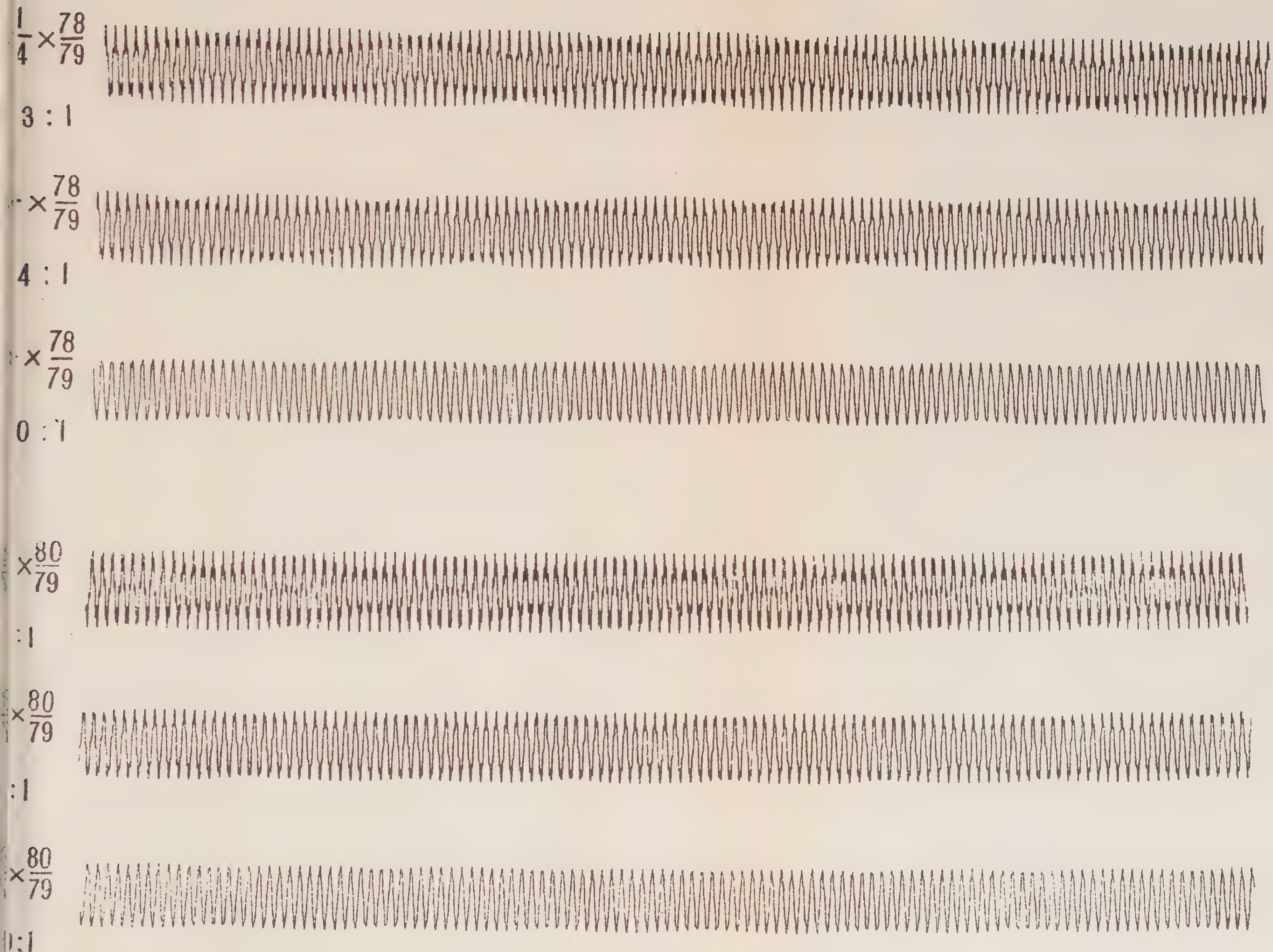
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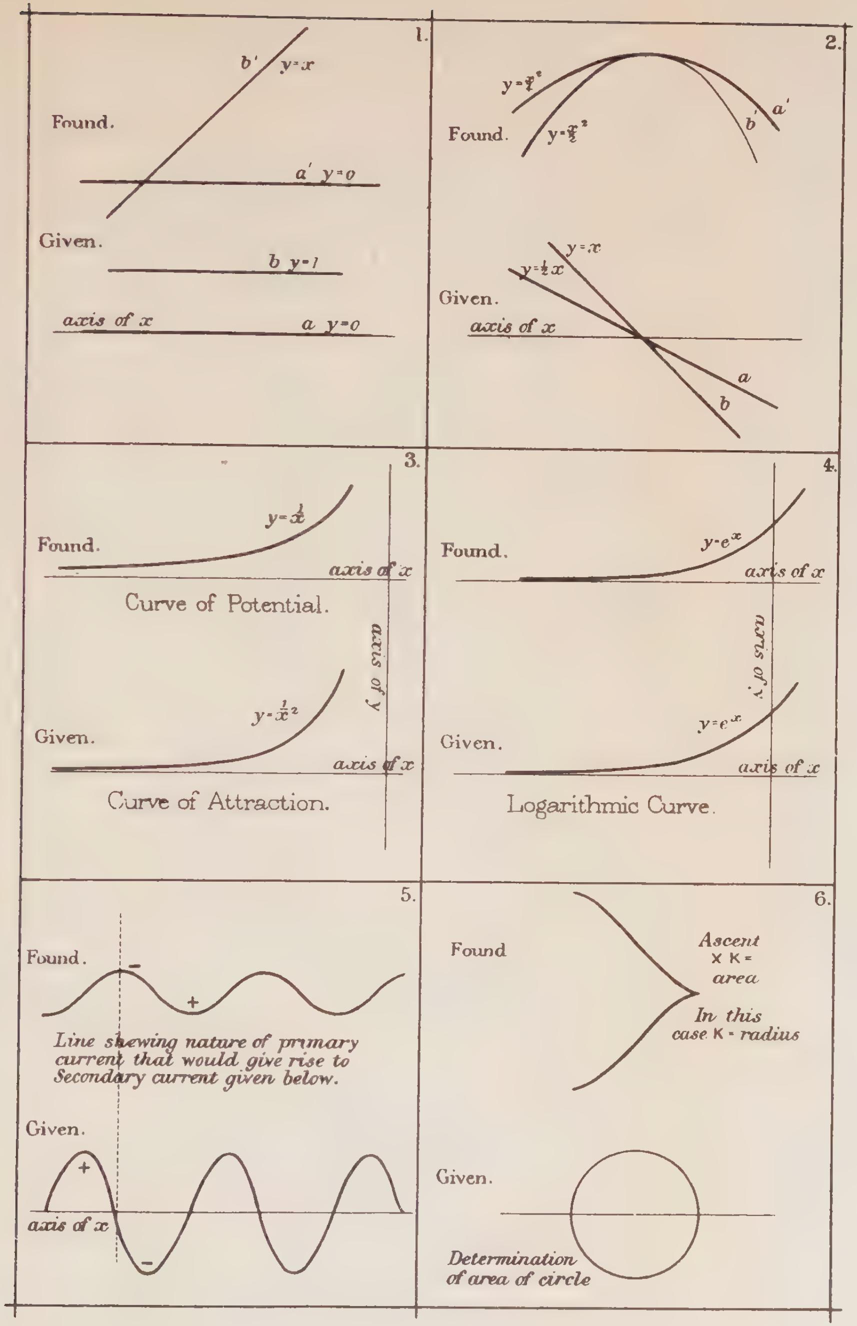

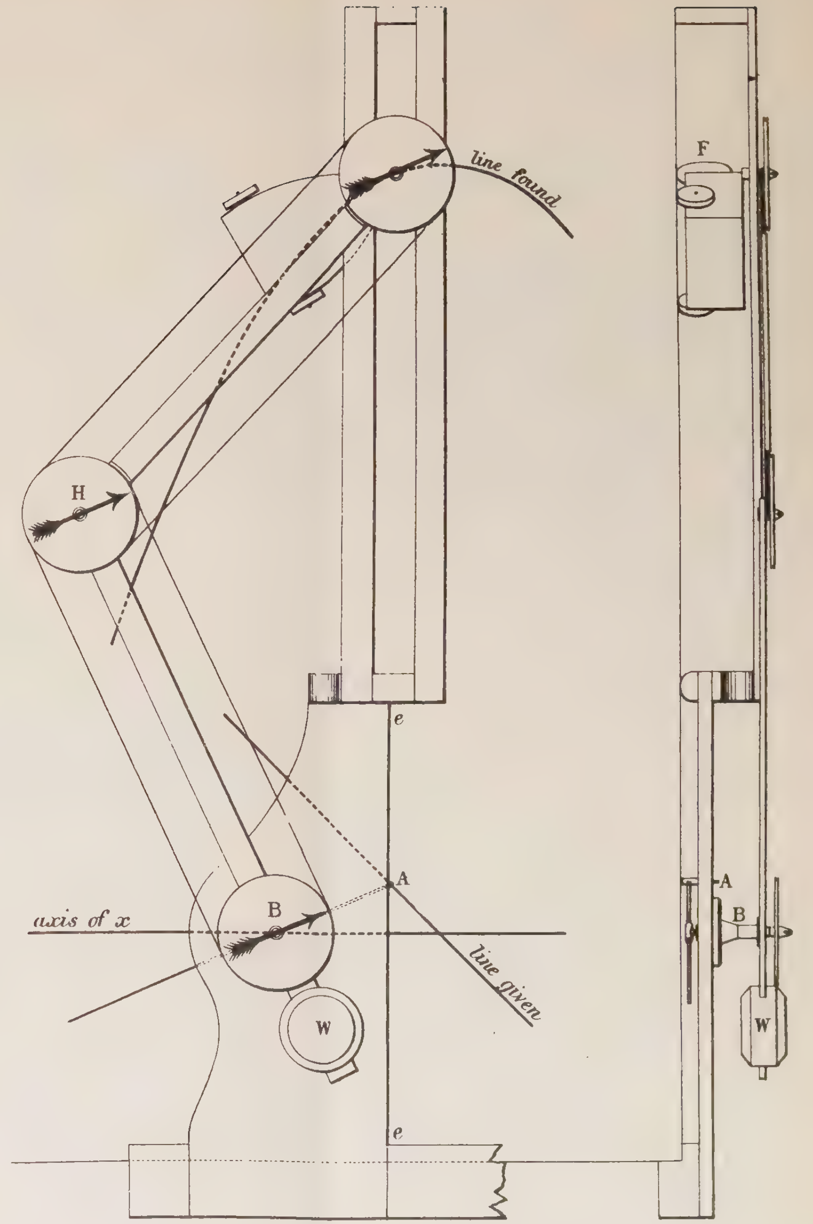

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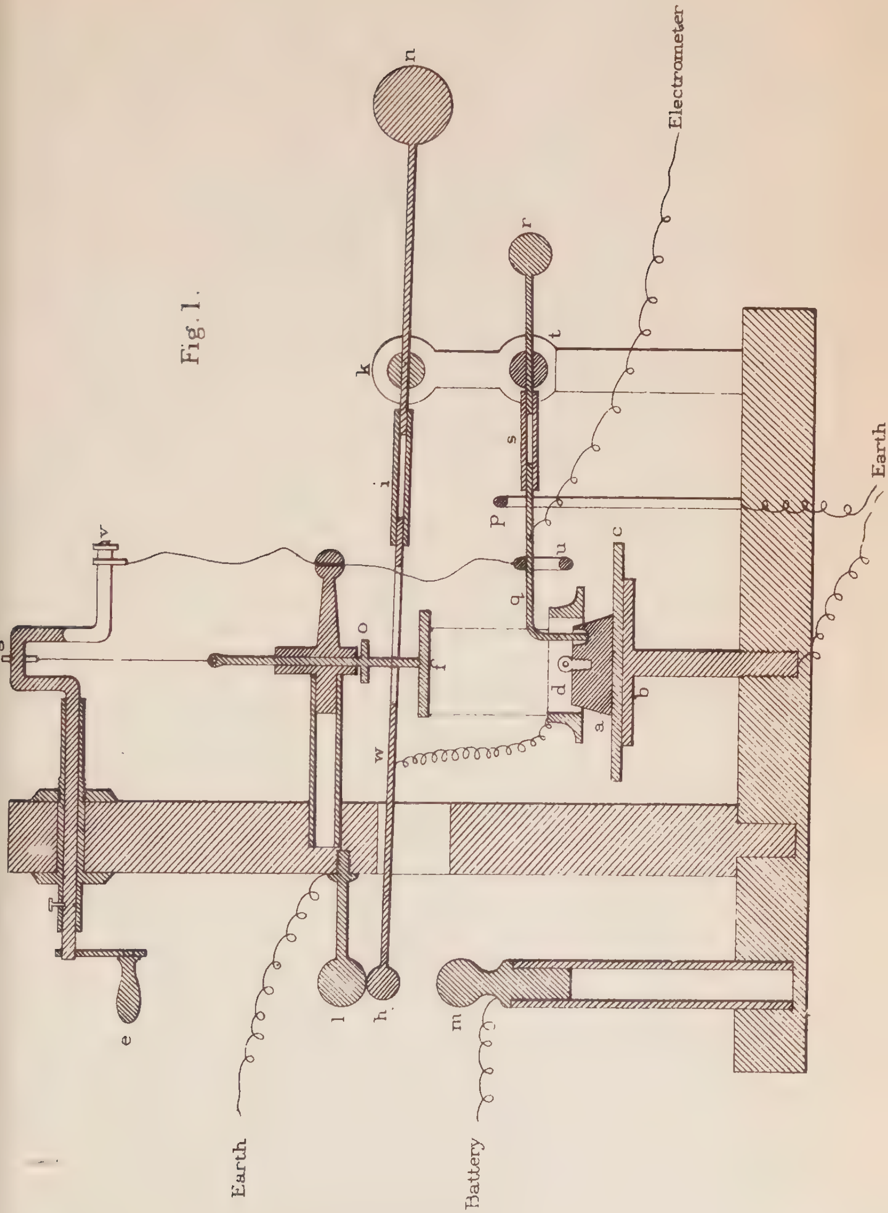

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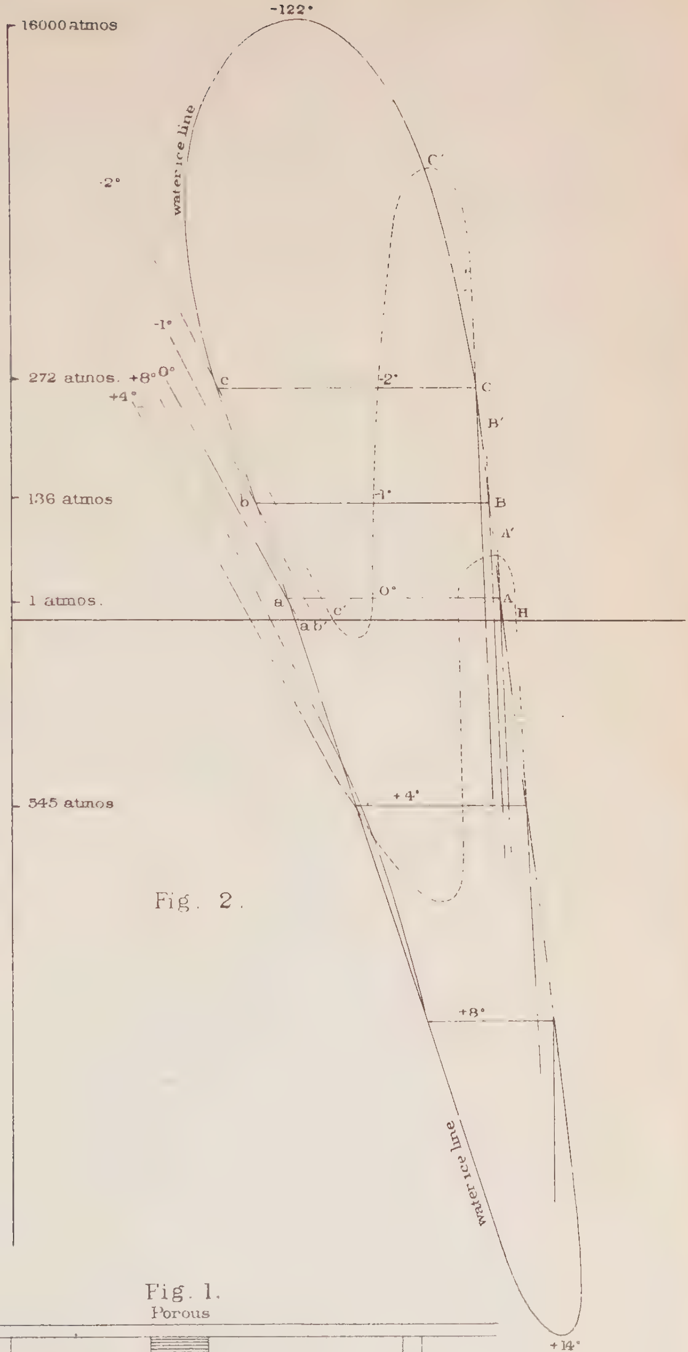

Fig. 2.

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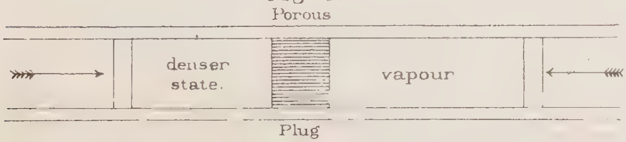

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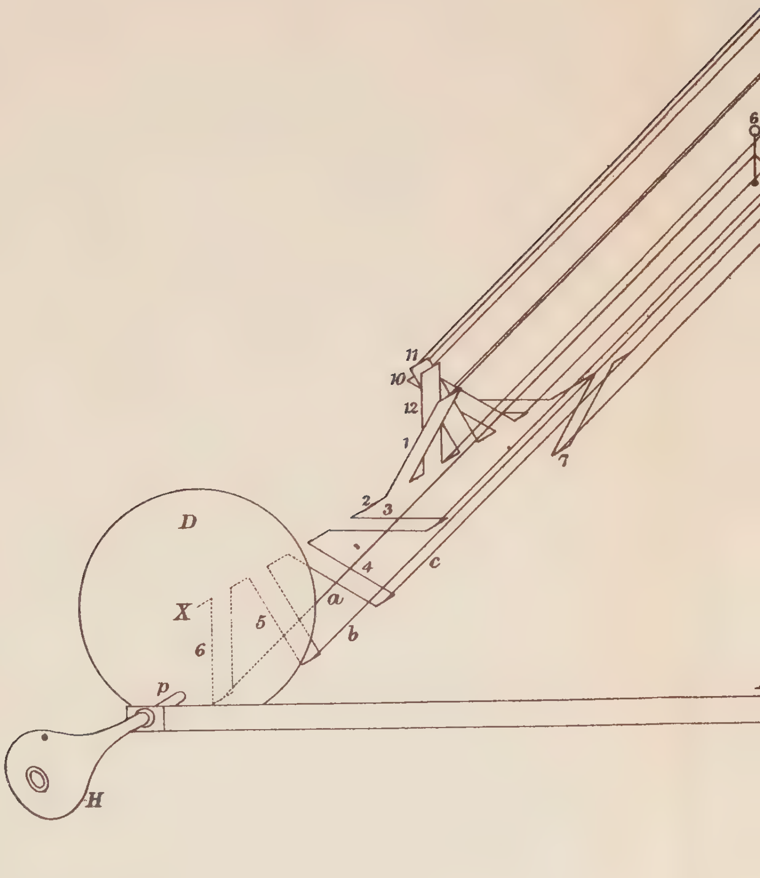

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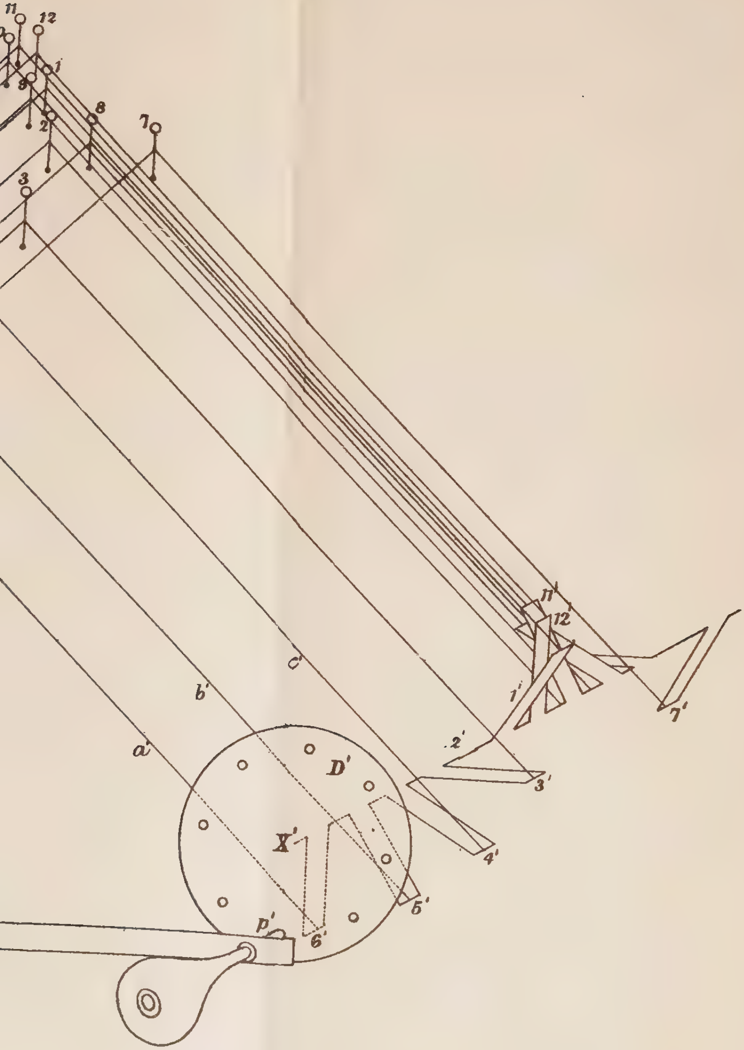

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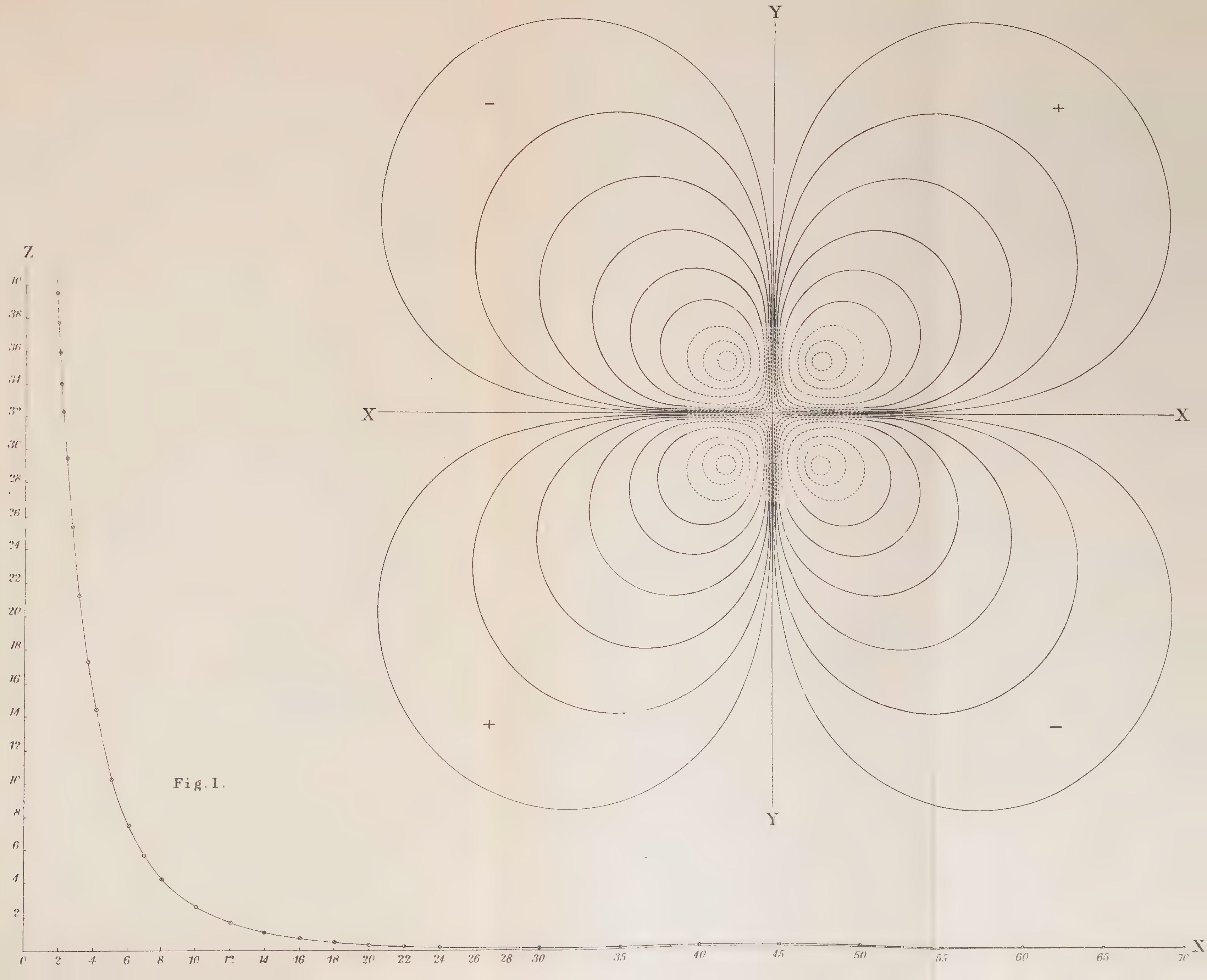

Fig. 1.

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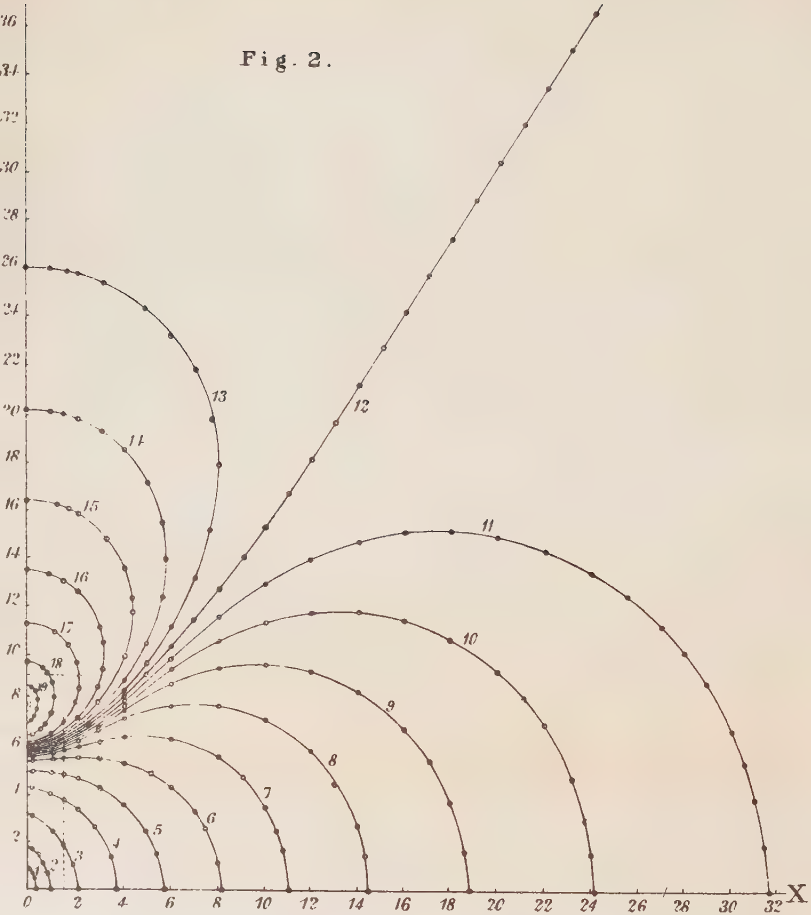

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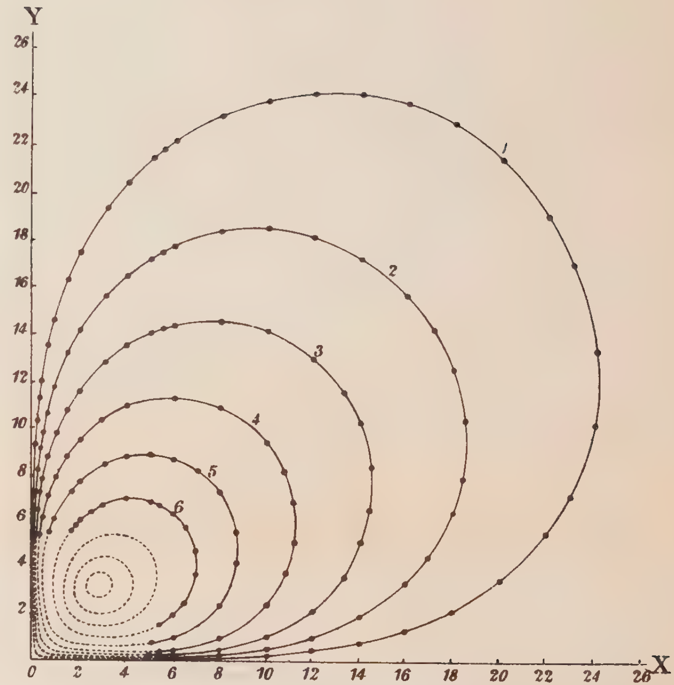
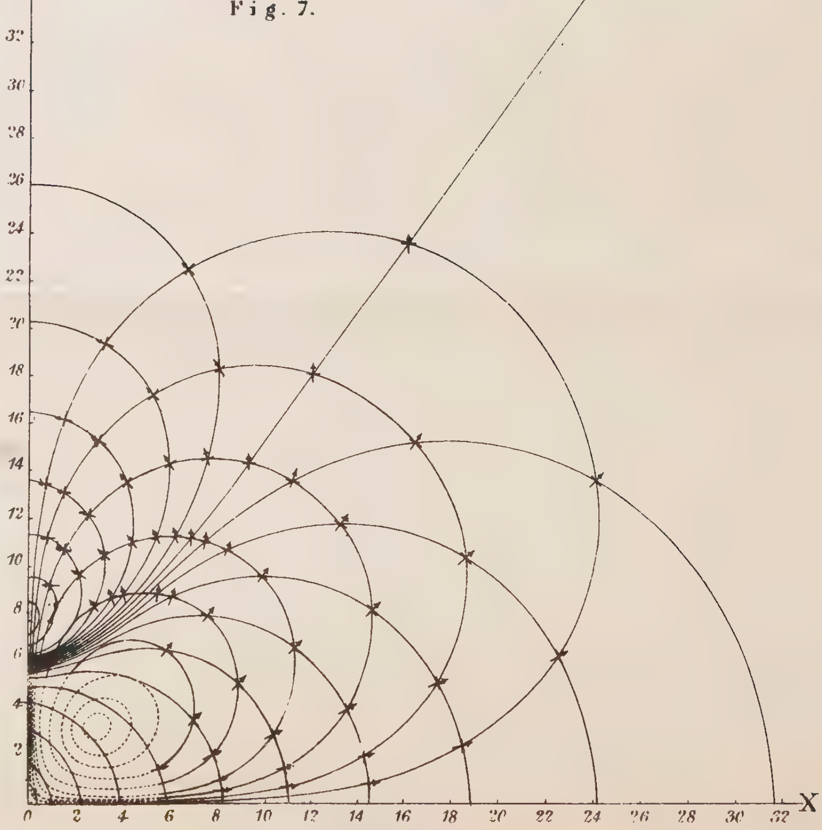


Fig. 7.



Mintern Bro's lith.

PROCEEDINGS

AT THE

MEETINGS OF THE PHYSICAL SOCIETY

OF LONDON.

SESSION 1880-81.

February 14th, 1880.

Prof. W. G. Adams, M.A., F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society:—

A. Mollison, M.A.; T. C. Lewis, M.A.; Señor Dr. Rafael Roig y Torres; A. T. Hare, B.A.; Miss Caroline A. Martineau.

The following papers were read:—

"On a Spectroscope with Telescope and Collimator Lenses achromatized by Quartz and Iceland Spar." By Dr. W. H. Stone.

"On an Automatic Electric Switch." By W. R. Wynne.

"Note on the Theory of Terrestrial Magnetism." By Profs. Ayrton and Perry.

February 28th, 1880.

Prof. W. G. Adams, M.A., F.R.S., Vice-President, in the Chair.

The following presents were announced:—

Bemerkungen über das Mechanische Æquivalent der Warme. By J. R. Mayer. Presented by Prof. S. P. Thompson.

The following papers, by Dr. Schuster, F.R.S. Presented by the Author:—

"On Unilateral Conductivity."

"On the Polarization of the Solar Corona."

"Experiments on Electrical Vibrations."

"On the Spectra of Metalloids (Oxygen)."

"Report of Total Solar Eclipse, April 6, 1875."

Ueber die Bestimmung der Breehungsenponenten mit totaler Reflexion. By Prof. Quincke. Presented by Dr. Schuster.

The following papers were read:—

"On some Effects of Vibratory Motion in Fluids." By R. H. Ridout.

"On the Pneumatic Experiment of Clement Desormes." By R. H. Ridout.

"On the Determination of Chemical Affinity in terms of Electromotive Force." By Dr. C. R. Alder Wright.

March 13th, 1880.

Dr. Huggins, D.C.L., F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society:—

Prof. G. M. Minchin, M.A.; James Hulme; Augustus Stroh; Prof. D. E. Hughes; Lieut. G. T. Wingfield, R.N.; J. Macfarlane Gray.

The following papers were read:—

"On the Surfusion of certain Metals." By W. C. Roberts.

"On a Novel Source of Electricity." By Prof. W. F. Barrett.

"On the Influence of Friction upon the Generation of a Voltaic Current." By Shelford Bidwell.

"Note on the Excitement of Electricity by the Friction of Non-conductors." By Prof. F. Guthrie.

"On the Efflux of a Liquid from an Expanded Pipe." By R. H. Ridout.

April 10th, 1880.

Prof. Fuller, M.A., in the Chair.

The following were elected Members of the Society:—

Prof. J. W. Judd, F.R.S.; W. O. Smith.

The following papers were read:—

"On the Human Eye as an Automatic Photometer." By W. Ackroyd.

"On Prof. Guthrie's Experiment relating to the Excitement of Electricity by the Friction of Non-conductors." By Profs. Ayrton and Perry.

"On Kœnig's Tuning-fork Clock." By Dr. W. H. Stone.

Dr. Guthrie exhibited an experiment indicating the magnetic behaviour of a *magnetic* iron cylinder rotating in front of a conductor carrying a current parallel to its axis.

April 24th, 1880.

Prof. W. G. Adams, M.A., F.R.S., Vice-President, in the Chair.

The following present was announced:—

Saunier's Treatise on Horology. Presented by Mr. Edward Rigg.

The following were elected Members of the Society:—

The Marquis of Blandford; John Marshall, F.R.A.S.

The following papers were read:—

"Preliminary Note on Mr. Hall's recent Discovery of the Displacement of the Current in a Conductor of Magnetic Force." By Prof. H. A. Rowland.

"On a Correction to be applied to the Indications of the Bifilar Magnetometer, and also a new Method for the Absolute Measurement of the Horizontal Intensity." By H. Wild.

"On new Thermoelectric Apparatus." By R. H. Ridout.

Mr. Ridout also exhibited Apparatus for showing electrolysis, for measuring cohesion in liquids, for showing absorption of heat on liquifaction, and for showing production of musical notes in a continuous tube.

Dr. W. H. Stone exhibited photographs of Kœnig's Tonometer.

Prof. G. M. Minchin described some experiments he had recently made on photo-telegraphy.

May 8th, 1880.

Sir William Thomson, LL.D., F.R.S., President, in the Chair.

The following were elected Members of the Society:—

E. F. Bamber, C.E.; Dr. Eugen Obach; Prof. H. E. Roscoe, F.R.S.; R. D. Turner, F.G.S.; Henry Watts, F.R.S.; Edward Woods, C.E.

The following papers were read:—

"On Photo-Electricity." By Prof. G. M. Minchin.

"A new Form of Electrometer-key." By Dr. O. J. Lodge.

"On the Elimination of Air from Water." By Sir William Thomson.

"On Steam-Pressure Thermometers. By Sir William Thomson.

"On the Radiation of Water-Steam Pressure Thermometers." By Sir William Thomson.

May 22nd, 1880.

At the Cavendish Laboratory, Cambridge.

Lord Rayleigh, F.R.S., Vice-President, in the Chair.

Mr. W. N. Shaw exhibited an apparatus for distilling mercury at low temperatures.

Mr. Sedley Taylor exhibited an adaptation by Kœnig of an arrangement of Sir John Herschel's for studying the interference of sound; also an improvement on Powell's wave-apparatus.

Mr. Poynting described an arrangement for measuring the plane of polarization of light.

Mr. Glazebrook showed a different apparatus for the same purpose.

Lord Rayleigh gave an account of some observations he had made relating to the theory of colour.

The Members afterwards visited the various departments of the Cavendish Laboratory.

June 12th, 1880.

Dr. HUGGINS, F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society:—

C. V. BOYS; ADAM HILGER; H. B. JUPP, F.R.S.

The following papers were read:—

"On the Earth's Rotation as influenced by Solar Energy." By Dr. SHETTLE.

"On the use of Interference-Bands for obtaining Indications of the Pressure of a Gas, and on the Passage of Electricity through Gaseous Media." By Prof. E. WIEDEMANN.

"On a Simple Method of Amplifying small Vibrations." By R. H. RIDOUT.

"On the Radiograph." By D. WINSTANLEY.

"On the Mathematical Explanation of the Figures of the Phonci-doscope." By WALTER BAILY.

June 26th, 1880.

Prof. W. G. ADAMS, M.A., F.R.S., Vice-President, in the Chair.

The following papers were read:—

"On Magneto-Electric Induction (Resistance of Liquids)." By F. GUTHRIE and C. V. BOYS.

"On the Refraction-equivalents of Isomeric Bodies." By Dr. J. H. GLADSTONE.

"On a Fire-damp Indicator." By Mr. LIVEING.

"Vacuum-tube of varying Resistance." By Dr. W. H. STONE.

"On Specific Heats calculated from Entropy." By J. MACFARLANE GRAY.

"On the Behaviour of Liquids and Gases near their Critical Temperatures." By J. W. CLARK.

"On some Varieties of Air-thermometer and a Thermograph." By D. WINSTANLEY.

"On a Modification of Bunsen's Ice-Calorimeter." By W. W. GEE and W. STROUD.

Dr. W. HUGGINS exhibited Photographs of Star Spectra and a Photograph of the Spectrum of Water.

November 13th, 1880.

Prof. W. G. ADAMS, M.A., F.R.S., Vice-President, in the Chair.

The following papers were read:—

"On the Beats of Mistuned Consonances of the form $h:1$." By R. H. M. BOSANQUET.

"On Action at a Distance." By W. R. BROWNE.

"On the Thermodynamic Relations of the Thermal and Ergonal Constituents of Heat in Liquids, Vapours, and Gases." By J. MACFARLANE GRAY.

"On Professor Exner's papers on Contact Electricity and Polarization." By Profs. AYRTON and PERRY.

Prof. MINCHIN exhibited a Photoelectric cell.

November 27th, 1880.

Prof. W. G. ADAMS, M.A., F.R.S., Vice-President, in the Chair.

The following was elected a Member of the Society:—

H. CHAPMAN JONES, F.C.S.

The following papers were read:—

"On the Photophone." By Prof. A. GRAHAM BELL.

"On a Modification of Prof. Graham Bell's Photophone." By SHELFORD BIDWELL.

"On Refraction-equivalents." By Dr. J. H. GLADSTONE.

December 11th, 1880.

Prof. W. G. ADAMS, M.A., F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society:—

WALTER RALEIGH BROWNE, M.A.; T. WRIGHTSON, C.E.

The following papers were read:—

"On the Rate of Decrease of Light from Phosphorescent Surfaces." By Lieut. DARWIN, R.E.

"On the Determination of Chemical Affinity in terms of Electromotive Force." By Dr. C. R. ALDER WRIGHT.

January 22nd, 1881.

Dr. GUTHRIE, F.R.S., and afterwards Prof. W. G. ADAMS, F.R.S., Vice-President, in the Chair.

The following was elected a Member of the Society:—

G. P. SIMPSON.

The following papers were read:—

"On the Construction of the Photophone." By Prof. S. P. THOMPSON.

"On a Method of measuring Small Resistances." By R. T. GLAZEBROOK.

"On a Method of comparing the Capacities of two Condensers." By R. T. GLAZEBROOK.

Annual General Meeting.

February 12th, 1881.

Prof. Sir WILLIAM THOMSON, LL.D., D.C.L., F.R.S., President, in the Chair.

The following Report of the Council was then read by the President:—

If in the past year the history of the Society has been uneventful, the objects in view when it was formed have been steadily pursued.

The number of Members has risen from 298 at the last Annual General Meeting to 321 at the present time. Fifteen Members have compounded during the past year, and three have resigned. The number of papers read shows a slight increase, and their interest and value has been well sustained.

With regard to publications other than the 'Proceedings,' it may be mentioned that the Council have had considerable difficulty in obtaining the services of a translator possessing both scientific knowledge and a thorough acquaintance with the Italian language,

and in consequence some delay has occurred in translating Volta's work. Progress is, however, now being made; and additional help in the work of translation is being obtained.

The delay is perhaps of less importance, as the Council has decided to undertake the publication of a complete edition of Mr. Joule's scientific papers. In this they have not only the assent but the warm and active cooperation of this distinguished Physicist, who has voluntarily taken upon himself the collection of his papers.

Early in the year the Society of Arts requested the Council to nominate a recipient for the Albert Medal, which is awarded annually for "distinguished merit in promoting Arts, Manufactures, or Commerce." After careful consideration, the Council unanimously determined that Dr. Joule's name should be submitted to the Society of Arts as well deserving the honour; and the Council is gratified to find that the suggestion was adopted, the grounds for the award being stated as follows:—"For having established, after most laborious research, the true relation between heat, electricity, and mechanical work, thus affording the engineer a sure guide in the application of science to industrial pursuits."

The Library has continued to receive valuable contributions, both from learned Societies at home and abroad, in the form of their 'Transactions' and 'Proceedings,' and from private individuals. One of the most interesting of the latter class is a volume of Minutes of a Society kindred to ours, which appears to have existed about the years 1794–95*. This volume, presented to the Society by Mr. Latimer Clark, contains evidence of the great intellectual activity at that time; and some of the experiments referred to are identical with some of those of our own day, although, of course, differently interpreted.

Your Library Committee will shortly seek for a grant out of the Society's funds for the purpose of completing and binding certain periodicals and pamphlets. The Committee would also urge upon the Members of the Society that, as the Library is still small, serious efforts should shortly be made for its proper organization and development, so that it may keep pace with the growth of the Society.

A Meeting of more than ordinary interest was held on the 22nd

* "The Minutes of the Society for Philosophic Experiments and Conversations." T. Cadell and W. Davies, Strand, 1795.'

of May at Cambridge, in the Cavendish Laboratory, by the invitation of Lord Rayleigh, and the Meeting was rendered specially pleasant by the kindness of the Master and Senior Fellows of St. John's College, who placed their library and combination rooms at the disposal of the Society.

With regard to the Funds of the Society, the Council, in October last, sought the legal advice of one of our Members, Mr. Frank Crisp, who wrote as follows:—"No provision is made in the Bye-Laws for investments, and the Council are therefore in the same position as Trustees in whose trust-deed nothing is said as regards investments." The Council has therefore no legal power to invest in such profitable sources of income as Railway Debentures or Preference Stock, and, in order that the necessary authority may be obtained, Mr. Crisp has kindly prepared the resolution that will be submitted to you to-day.

The Council is satisfied that the Society has been grateful to the Vice-Presidents, on whom, in the absence of our distinguished President, more than an ordinary share of duty has fallen.

The Society has to regret the loss of two Members by death. On the 8th of February, 1880, Sir THOMAS FREDERICK ELIOT died at Cairo, from typhoid fever. He was the son of the Rt. Hon. Hugh Eliot, sometime Governor of Madras. He was born in London in 1808, and was educated at Harrow. In 1825 he entered the Colonial Office, and was Secretary to the Earl of Gosford's Commission in Canada from 1835 to 1837, when he was appointed Chief of the first Department of Emigration in this country, an office which he held until 1847. From that date to the end of 1868 he held the post of Assistant Under Secretary of State for the Colonies, and he was nominated a Knight Commander of the Order of St. Michael and St. George in 1869. He was twice married, and survived his second wife but a few days. He joined this Society in 1879, and by his death we lose a distinguished Member of high official rank, who always had the advancement of science at heart.

The Rev. ARTHUR RIGG, M.A., who died on the 2nd September, 1880, at the age of 68, will long be remembered as one of the early pioneers in the cause of Technical Education. He was born on the 10th of March, 1812, at Carlisle, and received his early education at Warrington and in the Isle of Man. Matriculating at Christ's College, Cambridge, in 1832, he graduated in 1835 as 27th Wrangler, was immediately afterwards ordained, and was appointed Senior Mathematical and Philosophical Master at the Royal Insti-

tution in Liverpool. About this time there was much interest taken throughout the country in the question of training teachers for Church of England schools, and a highly influential meeting was held at Newton, near Warrington, on the 25th January, 1839, at which the details of a diocesan system of education were arranged, and it was resolved to build a large training college at Chester. Mr. Rigg was appointed its first Principal, and the College was opened in 1842, arranged to accommodate "50 training masters and 70 commercial scholars, together with all the officers of the establishment; and also 110 daily scholars in the modern school:" this latter was specially provided in order to afford the training masters actual practice in the teaching of such pupils as would subsequently be placed under their charge. From the first the advisability of combining with a sound intellectual education, instruction in the various manual trades was kept steadily in view. Besides the ordinary subjects taught in schools, the system of education comprised book-keeping, surveying, engineering, natural philosophy, and linear drawing; and the pupils, besides laboratory practice, were familiarized with the details of operative work; and in the workshops of the place they enjoyed an opportunity of becoming acquainted with the use of tools, the construction of machinery, the application of steam, principles of mechanics, statics, &c. In 1860 the school was certified as possessing all the requisites for the preparation of candidates for the Engineering Department of Public Works in India, and in the course of the next few years a considerable number went out to India in that service. Mr. Rigg resigned the Principalship in 1869, when nearly all of those who commenced the work with him had either died or left the diocese. He was a life member of the Society of Arts, a member of the Board of Visitors of the Royal Institution, a past member of the Institution of Mechanical Engineers, and an original member of our Society.

The Council would again call attention to the obligation under which the Society rests to the Lords of Committee of Council on Education for the use of the Physical Lecture Room and Laboratories so generously placed at its disposal; and they would also thank Dr. Guthrie, to whom the success of the Society is so largely due, for his important services as Demonstrator.

The Society then proceeded to the election of Council and Officers for the ensuing year; and the following gentlemen were declared duly elected:—

President.—Sir Wm. Thomson, LL.D., F.R.S.

Vice-President (who has filled the Office of President).—Prof. W. G. Adams, M.A., F.R.S.

Vice-Presidents.—Prof. R. B. Clifton, M.A., F.R.S.; Prof. F. Fuller, M.A.; W. Huggins, D.C.L., F.R.S.; Lord Rayleigh, M.A., F.R.S.

Secretaries.—Prof. A. W. Reinold, M.A.; Prof. W. Chandler Roberts, F.R.S.

Treasurer.—Dr. E. Atkinson.

Demonstrator.—Prof. F. Guthrie, Ph.D., F.R.S.

Other Members of Council.—Prof. W. E. Ayrton; Walter Baily, M.A.; Prof. J. H. Cotterill, M.A., F.R.S.; Prof. G. C. Foster, F.R.S.; J. Hopkinson, M.A., D.Sc., F.R.S.; R. J. Lecky, F.R.A.S.; Hugo Müller, Ph.D., F.R.S.; Prof. Osborne Reynolds, M.A., F.R.S.; Prof. A. W. Rücker, M.A.; A. Schuster, Ph.D., F.R.S.

The following were elected Honorary Members:—

John William Draper; Gustav Wiedemann.

After the names of the Council and Officers had been announced from the Chair, votes of thanks were passed:—to the Lords of the Committee of Council on Education; to the President; to Prof. Guthrie for his valuable services to the Society; to the Officers; and to the Auditors.

THE TREASURER IN ACCOUNT WITH THE PHYSICAL SOCIETY, FROM DECEMBER 31ST, 1879, TO DECEMBER 31ST, 1880.

Dr.	£	s.	d.	£	s.	d.
Balance in Bank				136	5	2
" paid by Treasurer				22	5	4
Entrance-Fees	£31	0	0			
Subscriptions for 1876	1	0	0			
" 1877	1	0	0			
" 1878	3	0	0			
" 1879	10	0	0			
" 1880	122	0	0			
" 1881	6	0	0			
Life Compositions	150	0	0			
				324	0	0
One year's Dvidend on £400 4 per cent. Furness Debenture Stock, less Income Tax, 6*s*. 8*d*.				15	13	4
One year's Dividend on £460 5 per cent. Midland Preference Stock, less Income Tax, 10*s*. 1*d*.				22	9	11
Sales in 1879:—						
Everett	£6	10	4			
Wheatstone	7	6	3			
Proceedings	2	2	0			
Sales to December 1880:—						
Wheatstone	5	12	6			
Proceedings	2	6	0			
	23	17	1			
Commission	2	7	8			
				21	9	5
				£542	3	2

Cr.	£	s.	d.	£	s.	d.
Expenses of Soiree:—						
King's College	£28	19	0			
Petty Expenses	1	11	9			
Printing &c.	4	4	9			
Use of Piano	2	14	0			
				37	8	6
Library:—Williams and Norgate				3	1	6
Reports of Meetings				14	15	6
Chapman:—						
Attendance	2	15	0			
Petty Cash	1	5	0			
				4	0	0
Purchase of £200 Metropolitan Board of Works Stock				210	0	0
Messrs. Taylor and Francis:—						
Vol. iii. part iii., Proceedings	30	0	0			
Postage and addressing	2	19	0			
Members' extra copies	7	0	0			
Vol. iii. part iv., Proceedings	25	6	6			
Postage and addressing	3	9	0			
Members' separate copies	3	9	0			
Miscellaneous printing	13	15	8			
				85	19	2
Petty Cash:—						
Mr. Reinold	2	2	8			
Mr. Roberts	0	19	6			
Dr. Atkinson	2	4	0			
				5	6	2
Balance in Bank				167	13	10
" due by Treasurer				13	17	6
				£542	3	2

Audited and found correct,

SHELFORD BIDWELL, } *Auditors.*
WALTER H. COFFIN, }

London, February 2nd, 1881.

PROPERTY ACCOUNT OF THE PHYSICAL SOCIETY.

Assets.	£	s.	d.	Liabilities.	£	s.	d.
Subscriptions due	40	0	0	Cheque unpaid	4	0	0
£400 4 per cent. Debenture Stock Furness Railway at 103	412	0	0	Subscriptions in advance	6	0	0
£460 5 per cent. Midland Railway Preference Stock at 123	565	0	0	Balance	1398	11	4
£200 Metropolitan Board of Works Stock	210	0	0				
Due by Treasurer	13	17	6				
Balance in Bank	167	13	10				
	£1408	11	4		£1408	11	4

We have examined the above Account, and also the Securities at the Bank, and find the same to be correct.

SHELFORD BIDWELL, } *Auditors.*
WALTER H. COFFIN,

London, February 2nd, 1881.

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